University of Southern Queensland
Faculty of Health, Engineering and Sciences

Development of an Innovative Flooring System for Residential and Light Industrial Buildings

A dissertation submitted by

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Abstract

Due to Australia's current housing boom and drastic bushfires over recent years, there is a high demand for timber. This has forced long lead times, particularly for structural timber, due to limited alternatives available. This may be an opportunity for developers of innovative building systems to gain some market acceptance in the residential building industry that is normally very conservative and slow to adopt new building systems.

The traditional bearer and joist flooring system requires an extensive list of raw materials and many man hours to complete the job safely and effectively. Reducing material costs and on-site labour during construction would benefit the building industry. This study aimed to follow and document the development process of an innovative flooring system. This includes the design and testing of a structural beam and an innovative floor plank that can be used as flooring in residential and light industrial buildings. The building industry could be provided with a viable alternative to traditional flooring if these innovative building systems prove to have the structural capability after efficient research and testing.

A desktop analysis was performed to consider different material combinations and material thicknesses for the beam and plank. The theoretical analysis was used to assist with the best suited design for physical testing. One floor plank and one beam were manufactured. The plank was tested with a uniformly distributed load (UDL) and the beam with two-point loads. The loads applied were based on AS1170.1 - Minimum design loads on structures. The loads, deflections and failure modes were recorded and graphed during testing. The physical data was compared with the theoretical data to validate the outcomes and provide conclusions.

The physical testing validated the structural capability of both systems. It was proven that these innovative building systems provide a possibility for builders to save both time and money during construction. The results provided an opportunity to develop structural span tables for both building systems. These tables show the load capacities and limitations for each building system.

Theoretical analysis and physical testing proved both innovative building systems have the structural capability to compete with the traditional bearer and joist construction. Further investigation into material variables would benefit. Ongoing material refinement could improve the design and viability and broaden the use of these innovative building systems.

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Glossary of Terms

ABCB	Australian Building Codes Board
ACP	Aluminium Composite Panel
AS	Australian Standards
DTS	Deemed to Satisfy
EPS	Expanded Polystyrene
FSI	Flame Spread Index
GL17S	Glued Laminated Lumber
HWD	Hardwood
ICPs	Insulated Concrete Panels
IP	Intellectual Property
LVL	Laminated Veneer Lumber
NCC	National Construction Code
NDA	Non-Disclosure Agreement
OSB	Oriented Strand Board
PL	Point Load
RTI	Right to Information
SDI	Soke Developed Index
SIPs	Structural Insulated Panels
UDL	Uniformly Distributed Load

Australian Standards

AS1170.0-2002	Structural Design Actions – General Principles
AS1170.1-2002	Structural Design Actions – Permanent, Imposed and Other Actions
AS1170.2-2002	Structural Design Actions – Wind Actions
AS1366.3-1992	Rigid Cellular Plastic Sheets for Thermal Insulation
AS1530.3-1999	Methods for Fire Tests on Building Materials
AS1720-2010	Timber Structures
AS3600-2018	Concrete Structures
AS4100-2020	Steel Structures
AS4600-2005	Cold-Formed Streel Structures

1. Aims and Objectives

This thesis follows the creation of a new innovative building system that aims to provide an alternative to the traditional flooring systems. This dissertation intended to design and test an innovative flooring system that can be incorporated into residential and light industrial buildings. Developing a step-by-step development process for this floor system assisted in the development of future innovative building systems in the Australian building industry.

Completing a comprehensive literature review assisted in supporting the need for the chosen proposal. It provided a background knowledge and justified the intentions for the topic. The literature review aimed to review the existing bearer and joist non-fire rated flooring system and its limitations in the building industry. It reviewed the safety procedures for handling and installing the traditional bearer and joist flooring system. In addition, a costing exercise was performed to assess the overall costing involved in the traditional bearer and joist flooring system. If there are cost and installation benefits for the newly developed flooring system compared with the traditional system, the new system has a better chance of being accepted into the building industry.

A step-by-step development process for an Australia innovative building system was created to assess the product's potential for success. During this development step, the Australian innovative patent claim guidelines for the building system were submitted and assessed by a patent attorney. This thesis follows the development process rather than performing it.

The outcomes from the literature review and development process allowed for an informed assessment on the probability of this innovative building system being introduced into today's building industry. This building system was further validated through physical testing against the design criteria and modified as necessary.

If time and resources permit, a test installation was planned to be undertaken with potential floor coverings considered. This step aimed to assess the capability of the flooring system and identify any installation issues. Time did not permit to complete this step. Test installation and floor covering is to be tested at a later date once the final design is chosen.

This dissertation reviewed the existing bearer and joist flooring system and its limitations in the residential building industry. Assessing the safety procedures and costing involved introduced building gaps in the current system. A step-by-step development process for an Australian innovative building system was then be developed. This study evaluated and applied the appropriate Australian codes and standards for the proposed building system.

Entering this research topic, it became evident that the residential building industry has been generally resistance to change and acceptance of new flooring systems. The reasonings behind this was explored later in this thesis. Labour and material shortages can be the catalyst for new building systems to be accepted, as this may force builders to think differently.

2. Background

The traditional bearer and joist flooring system requires an extensive list of raw materials and many man hours to complete the job safely and effectively. Reducing material costs and on-site labour during construction would benefit the building industry.

The purpose of this thesis was to research and develop a non-fire rated prefabricated flooring system for the building industry. This involved developing a step-by-step development process for innovative building systems. Aspects like the planning, design, patenting, development, testing, manufacturing, distribution arrangements and marketing strategies were explored. This study designed and tested a beam and floor plank that can be used as flooring in residential and light industrial buildings. The building industry could be provided with a viable alternative to traditional flooring if these innovative building systems prove to have the structural capability after efficient research and testing.

The literature review researched the traditional flooring systems being used in today's Australian building industry. It explored the procedures for the traditional residential floor joists, bearers, particle board, sheeting, and wet area designs. Identifying the limitations of these processes provided possible improvements for the current flooring system.

During the research stages of this thesis, a desktop analysis was undertaken to fully understand the limits of the design. Different material combinations and material thicknesses for the beam and plank were considered during this analysis. The theoretical analysis assisted with the best suited design for physical testing. Physical testing was completed to validate the model and design. Material combinations and variations of the flooring panel design were explored using polystyrene, wood, metal sheet envelope, timber stringers, etc. Possible joining techniques and the benefits they could bring to the spanning capacity were validated throughout the research. Research and testing provided benefits from using each material including cost, strength, deflection, safety, and ease of installation, as well as end of life recyclable or repurpose possibilities.

It was important to understand the process for introducing innovative building systems, which need to comply with the National Construction Code (NCC). This code provides the minimum requirements for safety, health, and sustainability for innovative building systems.

Throughout this thesis, I have had a wonderful opportunity of being mentored through this real-life development process by a building systems innovator and a Structural Engineer. This process is not an easy or well documented pathway, and this thesis aimed to simplify the process and shine a light on the pathway for a non-fire-rated flooring system.

3. Literature Review

3.1 Assessment of Traditional Floor System

3.1.1 Overview

A floor framing system is designed to withstand the dead loads and live loads that are introduced throughout the buildings life span. There are a number of flooring systems that have been accepted by the building industry and considered well established and successful.

There are two main types of flooring systems in today's building industry:

1. concrete slabs and
2. bearer and joist flooring systems.

Concrete slabs are more commonly used on flat sites to give a solid and robust flooring system (Turner, L 2018). Design alternatives for concrete slabs are continuously being developed to better the environment, labour time and costing. The innovative flooring system has not been designed to compare with a slab on ground flooring system.

This innovative flooring system has been developed and tested to have the opportunity to compete with the typical bearer and joist flooring system. This flooring system is typically chosen for sites that are steep sloping. It is a lightweight approach that saves time and money on typical earthworks. The traditional bearer and joist flooring system can be made from timber, steel, or a combination of the two.

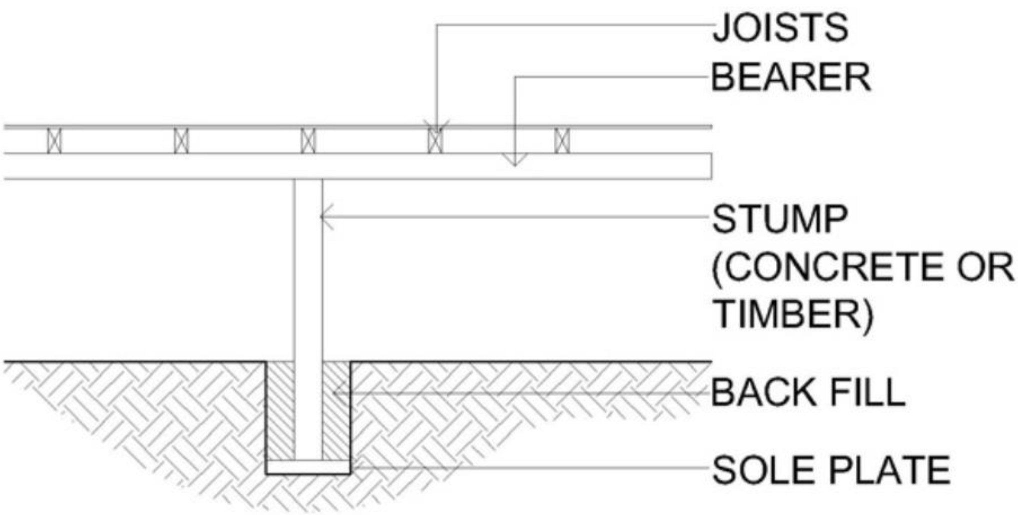


Figure 1 - Typical Residential Subfloor Section
https://www.thirdistudio.com.au/Types_of_Footings_In_Building.html

Timber framing has been a reliable and consistent flooring choice for residential housing for decades. Timber such as hardwood, glue laminated timber, and laminated-veneer lumber are common structural flooring bearers and joists for steep sloped sites. Willingham from the ABC news found that due to the COVID-19 pandemic, the industry has faced a home renovation boom due to less travel, more disposable income, and more home living. This paired with the dramatic bushfires over recent years has forced a high demand in structural timber. This has caused long lead times, due to limited timber alternatives available.

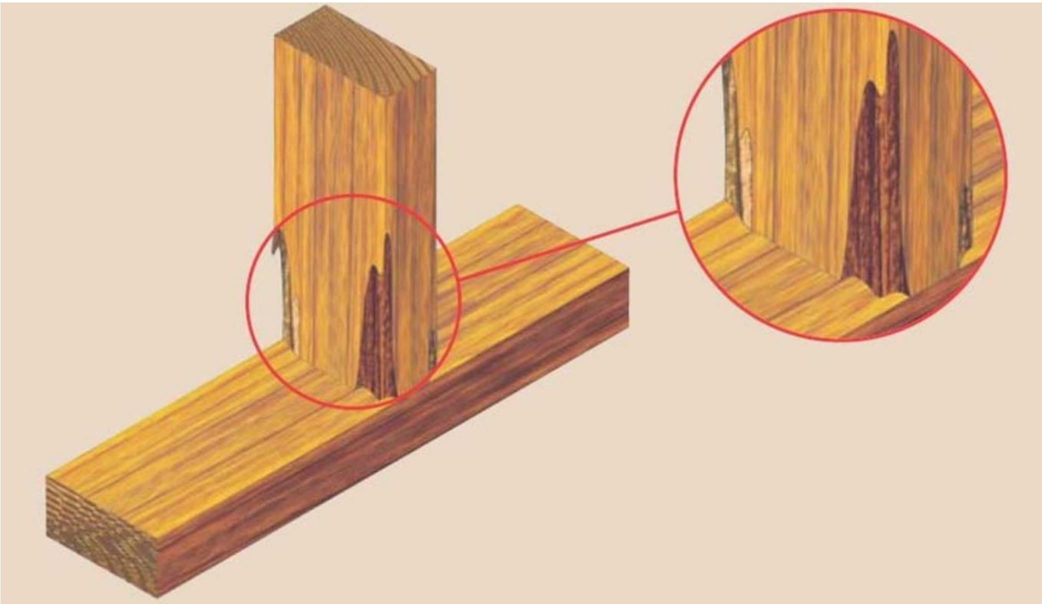


Figure 2 - Failure of subfloor construction leading to rotting of timber
https://www.uk.weber/facades/insulating-and-rendering-timber-framed-construction

Currently, steel framing is one of the main alternatives readily available in Australia. This system is a lightweight structure that provides a wide range of section sizes and capacities. The extent of a steel frame is continuously being developed and tested to provide greater structural adequacy in residential and industrial buildings. Stramit is an Australian steel company that develops and improves steel building products. Stramit has designed an Australian manual that provides builders with information regarding the load and spanning capacities for each of their products. They provide framing connections and installation guides that meet the performance requirements given in the NCC. Steel is a developed and tested alternative to timber that provides the opportunity for extended strength and durability for its uses.

This thesis followed the creation of a new innovative building system that aimed to provide an alternative to the traditional flooring systems. After a thorough development process, this new flooring system was designed to be incorporated into residential and light industrial constructions. Once fully developed, certified, manufactured and marketed to the building industry, the developers believe this system will have some unique benefits that will allow it to stand out as a viable alternative to traditional flooring systems.

3.1.2 Advantages

Timber floor framing provides a good variety of options for both function and aesthetics. Although timber is not fire resistant, it provides a slower rate of heat transfer when compared to other flooring choices (Timber Queensland 2015). Timber is a natural insulator, which decreases the need for cooling and heating for the building. Timber is a sustainable flooring system that is environmentally friendly.

The Tilling Group is an Australian company that is comprised of a number of smaller business units that supply their own Engineered Wood Products.

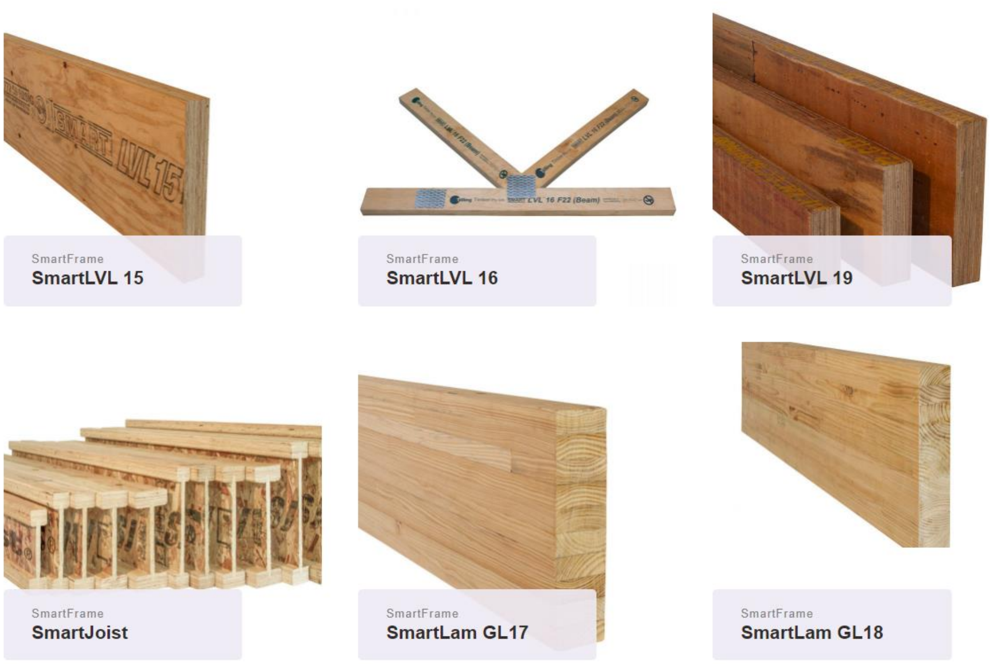


Figure 3 - Tiling Timber Range of Products
https://www.tilling.com.au/product/smartfloor/

Smart Frame is one company that manufacture and distributes a range of next generation structural timbers. These Australian engineered wood products are becoming a popular timber alternative to the typical seasoned hardwood. These engineered products provide greater opportunities for strength and durability. Smart Frame is regularly expanding their products to deliver to those in the construction industry looking for better solutions. Throughout the COVID-19 pandemic, the industry has faced a home renovation boom due to less travel, more disposable income, and more home living. This is forcing timber companies to have short supply on structural timber. This lumber shortage is affecting the construction industry as there can be up to 6 months lead time for delivery. This is forcing the industry to think differently when it comes to building alternatives.

The majority of structural steelwork and steel framing is prefabricated which offers a fast construction rate. The materials used in steel framing provide an increased quality control when compared with timber framing (Specifier Australia, 2021). Smart quality control involves reducing risk and creating better processes when it comes to construction sites. Specifier Australia found that on average it took approximately 800-man hours to complete a steel framed residence in Brisbane. Steel frames are lighter than concrete structures without compromising strength. Using steel framing for residential building provides design and construction benefits when it comes to sustainability.

3.1.3 Disadvantages

Studies show that timber floor framing is commonly affected by humidity and temperature change. Timber swells in damp weather and shrinks in dry weather. Timber is also prone to cupping, crowning, and moulding over time. A potential hazard for timber framing is termite attack, which can affect the life span of the flooring. Specifier Australia proved that if timber framing is not treated properly with quality water-resistant components, the timber will be susceptible to mildew and mould (Specifier Australia, 2021). The NCC requires that buildings during construction and use, must reliably resist termite actions. This means termite resistant materials or termite management systems in accordance with AS3660.1 must be followed to provide protection of building where a subterranean termite hazard is present (Timber Queensland 2015). The use of highly resistant and durable timber is recommended by the NCC. Timber flooring require ongoing maintenance on the top surface. The cost of a timber floor is high and is very labour-intensive during installation. In Queensland, there is currently a lumber shortage mainly due to the impact of the pandemic. Early 2019 saw a slowdown in timber production, which resulted in reduced supply. This paired with the increased demand from homeowners has forced the price of structural timber to skyrocket. Studies from Specifier Australia show the average cost of timber frames is $15 per metre.

Steel framing is known for conducting heat which requires the need for insulation measures. Steel framing does not allow for flexibility as it cannot be altered on site (Specifier Australia, 2021). A steel flooring system is commonly more expensive when compared to the typical timber floor. This is due to extensive labour time both in the factory and on site.

3.1.4 Conclusions

The traditional flooring system is made up of timber bearer, joists, particle board flooring or often compressed sheet in wet area, bracing, etc. This flooring system is known to be very expensive, material heavy, and labour intensive.

Any reduction in cost and on-site labour will benefit the building industry. The traditional bearer and joist flooring system requires an extensive list of raw materials and man hours to complete the job safely and effectively. It is envisaged that this new innovative flooring system will provide an alternative replacement for the current timber floor. This provides a great time to introduce an alternative flooring system into the construction industry as builders are becoming more likely to change due to the increased material cost.

This innovative alternative flooring system comprises of a beam and a plank, otherwise known as a flooring cassette system, and has the potential to save both time and money for developers, builders, and the homeowner. The proposed laminated floor planks are a lightweight alternative, with less components than traditional, that will assist in a faster and safer installation. This alternative flooring system provides opportunities for a more economical use of limited resource timber. This flooring system will require minimal skills to install and has the potential to benefit builders due to reduced time, cost and skills required.

The fact that the residential building industry has been generally resistant to change, and acceptance of new flooring systems was explored later in this thesis.

This innovative building system will not be adopted into the building industry unless it provides a price advantage to users. The building industry is known to be resistant when it comes to introducing new and innovative systems. New building systems need to cost less and be easier or quicker to have a greater chance to succeed.

3.2 Current Building Alternatives

3.2.1 Findings

From tiny homes to shipping containers, Australia has introduced alternative building systems for decades. Each of these building systems have their individual manufacturing techniques and benefits to the industry. This review will assess what residential flooring systems are available and the innovations being introduced into Australia’s building industry. The outcome of this review will aim to identify current building alternatives in the market and how they may compare to the new innovative building systems.

3.2.1.1 Structural Insulted Panels (SIPs)

Structural Insulated Panels are an alternative to the traditional timber framed construction (Wood Solutions 2020). This product is available as a suspended floor, wall, and roof system, but currently most commonly used as wall systems.

Figure 4 - Typical Structural Insulated Panel (SIPS) Formation
https://www.woodsolutions.com.au/applications-products/structural-insulated-panel-systems-sips

This innovative building system consists of two outer layers of oriented strand board (OSB) sandwiched around an expanded polystyrene core. A sandwich panel gets a large part of its strength from the outer layers, in this case the timber skin. The strand board outer layer provides a loadbearing structural capacity for the system and has been designed to withstand the vertical and horizontal loads. The inside layer is often weaker and non-load bearing. In this case, the EPS centre is used mainly for insulating the system. This helps reduce the dependency on bracing and provide superior insulation. Original testing has ensured these panels are strong enough to resist the applied forces and stiff enough not to deflect under serviceability conditions. The development of these panels has provided spanning tables for builders to easily utilise during the design stages of a building. The sufficient design and testing stages have ensured the product complies with Australian testing standards and code requirements (Wood Solutions 2020). These panels give sufficient strength which can double as a bracing wall in residential housing. This sandwich panel has been designed and manufactured to the minimum fire requirements in the Australian Standard.

These panels are typically prefabricated in standard sizes or can be pre-designed and panels custom made for an extra cost. Being a prefabricated building system, this gives opportunity for significant reduction in on site labour. The panel thickness can be altered to suit thermal insulation requirements and assist in structural considerations like support connections, spline design, and system deflections (Wood Solutions 2020). The orientated strand board provides opportunities for various architectural finishes. Wall claddings can be nailed or screwed to the facing.

SIPs Industries are a building company located in Western Australia that has been supplying SIP products for over 50 years.

Market acceptance for innovative flooring systems has been deemed difficult due to tighter building safety standards and lack of appropriate guidelines. The NCC provides a uniform set of regulations designed to establish essential construction standards for structural adequacy, fire resistance, and public health for an innovative flooring system (NCC 2021). New building systems must demonstrate compliance to allow product acceptance through the NCC. The design process is an iterative procedure for all flooring structures that must satisfy the pathway set out in the NCC. The current NCC only provides designers with general information exploring the relevant issues and standards to be considered when planning and designing an innovative flooring system. This could be a reason why innovative flooring systems entering the Australian building industry is deemed difficult. The NCC defines the function of the footing is not only to distribute vertical loads from the building to the foundation, but to ensure that the building superstructure performs satisfactorily (NCC 2021). This home renovation boom causing long lead times for structural timber could force the Australian building industry to think differently when it comes to building alternatives. This may be an opportunity for developers of innovative building systems to gain some market acceptance in the residential building industry that is normally very slow to adopt new systems. Increasing innovative product market acceptance and adoption is the first step for product acceptance.

3.2.1.2 Smart Floor by Tilling Timber

The Smart Floor Cassette System is an Australian building product that has been developed to minimise on site work and labour costs. This flooring alternative is a prefabricated system that increases the quality control on a construction site.

Figure 5 - Smart Floor Cassette System
https://www.tilling.com.au/product/smartfloor/

This flooring system is made up of various joists, beams, and floor sheets. They are precision cut and bonded together using a polyurethane adhesive (Tilling 2021). Pre-cut service holes are provided in each plank to preserve the integrity of the system. This flooring system utilises prefabricated structural timber that provides a lighter construction than its steel or reinforced concrete alternatives. The prefabricated lightweight construction provides opportunities for the panels to be lifted by cranes and laid into place. This in turn reduces the onsite labour and necessary construction skills to build using cassettes (Tilling 2021). Typical residential floors can be installed in under an hour. Being constructed solely from timber, it offers environmental benefits and sustainability opportunities. Timber construction provides speed of assembly as it is quicker to construct and easier to work with.

Smart Floor can be designed for a variety of sizes and range of thicknesses. Each variation of Smart Floor is designed to withstand the typical strength and load combinations set out in AS1170. Wet area and outdoor set downs can be incorporated into the design of the plank.

The Smart Floor Cassette System is design, manufactured, and distributed through The Tilling Group. Meyer Timber is another Australian building company that manufactures this type of cassette flooring system. In Queensland, businesses like Bunnings, Mitre 10, and many truss manufacturers produce, sell, and deliver this engineered flooring system.

3.2.1.3 Tec Beam by Tilling Timber

Tec Beam is a composite structural beam that comprises of timber flanges, galvanised steel web, and uniformly spaced service holes (Tilling 2021). This engineered beam has been designed and developed to provide options for structural beams, flooring systems, and roof solutions. This building system has been designed to withstand point loads and offset loads that are set out in AS1170.

The continuous steel web significantly enhances the Tec Beams stiffness when under load. The steel web also improves the shear capacity and strength of the system (Tilling 2021). The strength and stability of Tec Beam can be improved by increasing the size of the beam. Tec Beam is manufactured in five sizes and two thicknesses. Custom sized Tec Beams can be designed and manufactured to suit a variety of needs. Due to the steel web design, this building system can be used to achieve cantilevers in two directions (Tilling 2021). Structural analysed tables have been developed from each beam variable. Tec Beam can be installed in single or continuous span beams and floors.

Figure 6 - Tec Beam
https://www.tilling.com.au/product/tecbeam/

Tilling Timber provide design guides and installation guides for engineers and builders. Span tables have been developed for both residential and non-residential construction. The loading parameters are taken from the appropriate Australian Standard. In Queensland, businesses like Bunnings, Mitre 10, and many truss manufacturers produce, sell, and deliver this engineered beam.

3.2.1.4 XL-Floor – Insulated Flooring System

XL-Floor is a structural insulated flooring system that provides an insulated barrier between floors (Regen 2021). This flooring system is not designed to compare with the traditional bearer and joist flooring system, but instead has been developed to partner with the traditional system. The insulated flooring system can be used for suspended floors, multi-level constructions, and most commonly on stump construction (Regen 2021).

ReGen Building Solutions is a South Australian company who manufactures, assembles, and supplies these flooring systems nationwide. XL-Floor is manufactured as a 75 mm thick panel that is designed to manage both UDL and point loads.

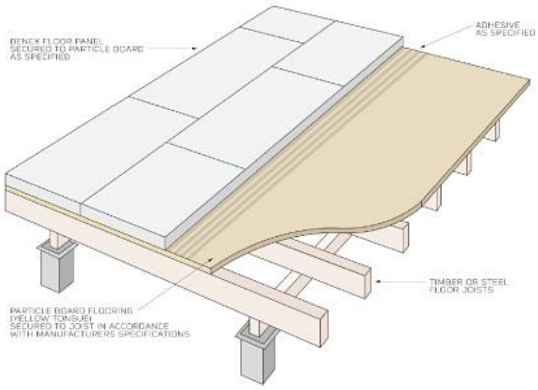


Figure 7 - XR-Floor

XL-Floor provides builders with fast installation as they are prefabricated panels, ease of installation due to the tongue and groove design and has options for surface finishes like tiles (Regen 2021). This flooring system has been designed and tested in accordance with that appropriate Australian Standards and Building Codes.

3.2.1.5 InsulLiving by Bondor

InsulLiving by Bondor is an Australian innovative insulated company that provides options for insulated walling and insulated roofing systems. This product provides a range of insulating core options for new homes, renovations, or modular buildings.

InsulLiving by Bondor is an Australian product. In 2007, Bondor completed a prototype home in Brisbane that showcased its wall and roof systems. A year later, the residential home achieved a 9.5-star energy rated living (InsulLiving 2021). After six years of research and development. This product has the potential to take Australia a step towards zero energy housing. Many residences around Australia have been built using this insulted panel system.

This innovative system provides designs for both wall and roof systems. The wall panel, InsulWall, comprises of a lightweight insulated core with a structural steel skin. The roof system, SolarSpan, combines roofing, insulation, and ceiling in one functional panel. It is evident that this innovative panel system does not have the capability to be provided as a flooring alternative for residential housing. Reasons for this will be explored later in this report.

The structural capability of both wall and roof systems have been tested and manufactured to suit Australia's current building standards. InsulWall requires no frame and has been designed to provide structural and load bearing panels. SolarSpan has been designed for larger spans which reduce the need for support structures (InsulLiving 2021). Bondors InsulLiving system is a fully engineered building product that complies with the Building Code of Australia. When the wall panel and roof panel are paired together, it provides a fully insulated structural shell. InsulWalls set of materials provide rendering options on the outside and direct finishing applications on the inside. SolarSpan provides a smooth ceiling without the need for plastering and painting.

Figure 8 - SolarSpan and InsulWall
http://www.insulliving.com.au/products

The overall benefits of this insulated panel provide for a faster residential construction (InsulLiving 2021). This design provides builders with design freedom, reduced costs and energy saving constructions. At this stage, these insulated wall and roof panels are not suitable for multi-storey residential construction, but this may change as they develop the panels to include more structural components.

3.3 Assessment of EPS

3.3.1 Evaluation of EPS

Expanded Polystyrene (EPS) is a lightweight closed cellular plastic material that has a range of remarkable characteristics. EPS is becoming a widely used building material in Australia's construction industry. Sulong (2019) believes this building material is capable of enhancing the design and structural integrity of a building. EPS was recognised as conventional insulation in the 1950's and has been progressing through the construction industry ever since. This could be due to its lightweight, low cost, and high thermal insulation properties. EPS is typically refined from oil and gas. It is then polymerised with a blowing agent and usually includes flame retardant modifiers. Sulong (2019) states that EPS is typically about 98% air that consists of small spheres in a closed cellular body. This provides a cost effective, recyclable, and versatile building material.

EPS is commonly paired with other building materials, to form sandwich panels, and further the structural integrity of floor, wall, and roof systems. Sulong (2019) provides an overview on the application of EPS in structural insulated panel applications. By introducing EPS through sandwich panels, it increases the performance characteristics and building applications. EPS posses a potential fire hazard with poor flammability and toxicity properties. This has created a concern in the building industry through hesitancy around using such product. This review will aim to assess the physical properties like fire performance, toxicity levels and current additives that are applied to the product for safety reasons.

Australia has developed a national standard that sets out the minimum properties for the six classes of EPS. AS1366.3 Physical Properties of Rigid Cellular Polystyrene. It outlines the density, compressive strength, thermal resistance, etc.

Physical Properties of EPS, according to AS 1366, Part 3 – 1992

Physical Property	Unit	Class						Test Method
		L	SL	S	M	H	VH	
Nominal Density (kg/m3)		11	13.5	16	19	24	28	N/a
Compressive stress at 10% deformation (min)	kPa	50	70	85	105	135	165	AS2498.3
Cross-breaking strength (min)	kPa	95	135	165	200	260	320	AS2498.4
Rate of water vapour transmission (max) measured parallel to rise at 23°C	$\mu g/m^2s$	710	630	580	520	460	400	AS2498.5
Dimensional stability of length, width, thickness (max) at 70°C, dry condition 7 days	%	1.0	1.0	1.0	1.0	1.0	1.0	AS2498.6
Thermal resistance (min) at a mean temperature of 25°C (50mm sample)	M^2K/W	1	1.13	1.17	1.20	1.25	1.28	AS2464.5 or AS2464.6
Flame propagation characteristics: - median flame duration; max - eighth value; max - median volume retained; - eighth value; min.	 S S % %	 2 3 15 12	 2 3 18 15	 2 3 22 19	 2 3 30 27	 2 3 40 37	 2 3 50 47	AS2122.1

Table 2 - Physical Properties of EPS – AS1366.3 Tb 2

The physical properties of EPS shown above have a range of classes and properties for different purposes. In Australia, insulated panels typically use an SL grade of EPS, which has a nominal density of 13.5 kg/m^3. This project will follow this guideline.

TABLE B1
RECOMMENDED APPLICATIONS OF RIGID CELLULAR POLYSTYRENE—MOULDED (RC/PS–M)

Class	Application
L	Decorative panels. Cavity and void forms.
SL, S	Insulation in walls, floors and ceilings; sandwich panels; insulated containers—all under low loads. Pipe and duct lagging—to operate at a maximum service temperature of 80°C.
M	Panels in walls, floors and ceilings; sandwich panels—all under medium loads.
H, VH	Insulated floors and roofs subjected to constant traffic of people and equipment.

Table 5 - Applications of EPS – AS1366.3 Tb B1

The NCC sets out the minimum technical requirements for new buildings in Australia. The purpose of this is to group buildings by their function and use. This innovative building system will follow the building codes for a single residential construction, building class 1. Buildings under this class of construction are typically standalone single dwellings of a domestic of residential nature. The classification summary of buildings and structures is covered in the NCC and can be founded as appendix TBC.

3.3.2 Safety Issues

Stec (2017) states that the toxicity of fire effluents is known to be the biggest cause of death and injury from unwanted fires. Synthetic polymers are known to burn more quickly and generate more smoke and toxic effluents than material materials. This area of study provides important information and data about the factors and properties of fire science.

Sulong (2019) provides an overview on the properties of EPS in terms of fire behaviour, moisture absorption, and toxicity levels. Exploring the physical properties of EPS assists the product designer in determining whether EPS is a viable building material for innovative building systems.

EPS is a strong and durable construction material that can pose safety issues if appropriate treatment is not followed. It is important that EPS when being used as a building material is compliant with the Australian Standard AS1366.3 which set guidelines for polystyrene products. Research and testing have been completed on building materials to determine their capability in certain aspects of building life.

Building material class		Designation
Class A	A1	Non-combustible materials
	A2	
Class B	B1	Not easily flammable
	B2	Flammable
	B3	Easily flammable

Table 8 - Building Material Classes

EPS is classified as a 'B3' building product, meaning it is easily flammable. Fire safety is an essential requirement that must be followed when designing a residential and light industrial building in Australia.

EPS is an organic material that is combustible and releases toxic gases when ignited. These gases include carbon dioxide, caron monoxide, water vapour and soot. EPS contains the toxic substance Styrene and Benzene that can pose issues to humans if untreated. Some popular treatments will be explored further in this review.

The National Construction Code establish minimum requirements for building material performance. Below is the standard flame and smoke ratings for EPS to deem to satisfy the appropriate Australian codes.

Flame and Smoke Ratings for EPS	
Flame Spread Index	Smoke Developed Index
< 25	< 450

Table 11 - EPS Index Ratings

The Flame Spread Index (FSI) provides the relative rate that a flame will spread across the surface of a treated material. It is calculated by the distance a flame travels across a material divided by the amount of time it takes to travel that distance. Testing involves burning the material under controlled conditions and measuring the speed and extent of flame spread. For class A buildings, the building materials must have a Flame Spread Index of 25 or less. This is set out in the National Construction Code to ensure all building materials deem to satisfy the minimum requirement. Concrete is the best fire-retardant building product but is not a viable substitute in this design.

$$Flame\ Spread\ Index = \frac{Distance}{Time}$$

The Smoke Developed Index (SDI) is a measure of the concentration of smoke a material emits as it burns. It is determined using the Steiner Tunnel Test. SDI measures the surface burning characteristics of a test specimen in a controlled environment. EPS typically generates an SDI of 450 or less. This is set out in the National Construction Code to ensure all building materials deem to satisfy the minimum requirement.

There is no fire rating for this class of construction, but there are limitations to what is given off in a fire situation. These limitations are explored in AS1530.3 – Methods for Fire Tests on Building Materials.

Like the building material timber, EPS burns when in contact with a flame. Sulong (2019) states that it is difficult to predict the behaviour of EPS in real fires from small-scale tests. The level of toxicity of EPS in a fire situation is no greater than that associated with timber. Both building materials produce the same toxic gas, carbon monoxide. It was concluded in 1980 by the TNO Centre of Fire Safety that the toxicity of the smoke fumes released from EPS is considerably less than those of other commonly used materials like wood and wool.

EPS began its construction life concealed behind drywall, sheet metal, or concrete. Over the last 30 years, there has been a rapid growth in the use of insulated panels as a construction material. This has given the construction industry an opportunity to develop and enhance the structural integrity of EPS. Today, most EPS products include a fire-retardant agent. It has been found that the thermal conductivity of EPS decreases as the foam density increases. This building material is best suited when insulated and sandwiched between two facings.

The Building Product Safety Alert warns building practitioners about the potential fire risks associates with the non-compliant use of expanded polystyrene when used as external wall cladding. The 2014 Lacrosse building fire is a devastating incident that happened to a Melbourne apartment building. The 21-storey building suffered a serious cladding fire that was started by a single cigarette on a balcony (Architecture, 2019). An aluminium composite panel (ACP) was used as external cladding on the Lacrosse building. ACPs consist of two thin foil-coated aluminium sheets bonded to an insulating polystyrene core. The panel is lightweight and rigid but is classified as a combustible building material. The NCC sets the requirements for the design and construction of all new building work.

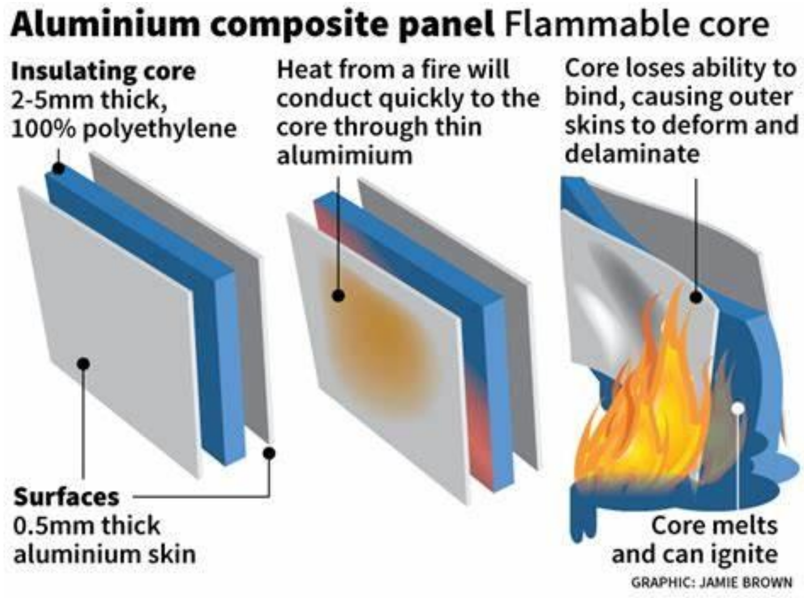


Figure 9 - Aluminium Composite Panels
https://harringtonlawyers.com.au/victorian-civil-and-administrative-tribunal-decides-on-lacrosse-cladding-fire/

The flames spread rapidly up the external wall cladding and propagated to the polystyrene core. This incident led to the discussion of fire safety risks presented by non-compliant use of combustible cladding. When exposed to fire, EPS is prone to melting, dripping, and collapsing. It has been found that when burning, expanded polystyrene releases 2.5 times the amount of energy as an equivalent amount to timber (VBA, 2018). By covering the expanded polystyrene with timber stringers and metal sheeting, it will minimise the risk of a melting system. It has been proven that the building material EPS is not unsafe or dangerous when installed in accordance with the NCC. Incorrect use of installation may compromise the safe use and render the product uncompliant (Architecture 2019). In the case study, it was proven that the composite sandwich panel failed to comply with the Deemed to Satisfy (DTS) provisions set out in the NCC. This scenario has highlighted the importance of building system developers to understand the insurance implications and risk mitigations when using specific building materials.

Certifiers believe that using EPS for certain constructions could pose problems if not designed for accordingly. Currently, EPS construction for single residential flooring systems is acceptable. However, it is prohibited to be used for apartment buildings with 2 or more stories, office buildings, and public buildings. This research provides opportunities to develop floorings using EPS for residential applications. However, it may be only a matter of time before this building material is banned for single residential applications in Australia.

3.3.3 Additives

All EPS suppliers must comply with the Australian Standard AS1366.3 – Physical Properties of Rigid Cellular Polystyrene. This code explores the physical properties of EPS and provide the minimum requirements for safety. Flame retardant EPS is produced by incorporating flame retardant additive during the manufacturing process. The presence of fire-retardant additives leads to significant improvements in the fire behaviour of EPS. Flame retardant aims to reduce the risk of accidental fire from small ignition sources. In Australia, EPS suppliers must provide flame retardant EPS to all building applications. The primary flame retardant currently being used as an EPS flame additive is hexabromocyclododecane (HBCD). This allows the foam to shrink rapidly away from the heat source, thus reducing the likelihood of ignition. This fire retardant may be added to expanded polystyrene to reduce the fire risk, but it does not prevent combustion from large fire sources.

It is important when dealing with EPS as a building material, the product follows the AS1366.3 code as well as the National Construction Code (NCC).

3.3.4 Knowledge Gap

After conducting an assessment on the building material EPS and reviewing the safety issues, a non-fire rated prefabricated flooring system was developed. There is no fire rating for this class of construction, but there are limitations on what toxic levels are given off in a fire situation.

Factors such as panel dimensions, foam density, and loading impacts were considered and assessed during the experimental stages of this thesis. This provided firsthand data that assisted in assessing the structural performance of this innovative system.

If future design and development is conducted on this flooring system, possible EPS alternatives could be considered like structural plywood. Structural plywood is a cheaper and is a strong building material when compared with EPS but is more labour intensive when it comes to manufacture and installation.

3.4 Summary of Literature Review Findings

A number of important findings were made as a result of this literature review. These findings assisted in uncovering new information that will contribute to the direction of this study.

- Due to Australia's current housing boom and bushfires over recent years, there is a high demand for timber, which have forced long lead times. This may give an opportunity for developers of innovative building systems to gain some market acceptance in the residential building industry.
- Reducing material costs and on-site labour during construction would benefit the building industry.
- EPS is a highly flammable building material, but with the presence of fire-retardant additives leads to significant improvements in the fire behaviour in a fire environment.
- It is strongly recommended that EPS should always be protected by a facing material.
- This research provides opportunities to develop floorings using EPS for residential applications. However, it may be only a matter of time before this building material is banned for single residential applications in Australia.

The literature review critically analysed the traditional flooring system, current innovative building alternatives as well as assessing the safety issues of EPS. This review provided valuable information on each of these topics which allowed the remainder of the thesis to be planned and conducted through the drive of past studies.

4. Implications

4.1 Consequential Effects

This research topic may present universal consequential effects around the outcome and needs to be considered to ensure 'best practice' can be achieved. Sustainability, safety, and ethical issues associated with this research will be identified and explored.

It is becoming more important that today's building systems are sustainable and environmentally friendly. The following points are sustainability considerations that were assessed during the development of this innovative flooring system.

- Reduction of raw materials: considered the environmental disruption of the traditional building system. Aimed to reduce the number of raw materials.
- Energy consumption: considered more energy efficient materials on the market and how they could be considered into the design.
- Emissions and waste: aimed to reduce the number of materials used as well as the end-of-life production.

Safety is an important aspect when it comes to building materials. All building materials should aim to be lightweight, non-hazardous, and allow for ease during manufacture and installation. This innovative flooring system has assessed and designed around each of these safety issues.

Ethical issues are an important responsibility for all engineers and entrepreneurs. The development of this flooring system has assessed the basic ethical issues and created adequate plans for delivery.

A more in-depth exploration into the consequential effects were identified in the risk assessment section of this thesis.

4.2 Ethical Responsibility

Engineers are known for their knowledge and skills that benefit the community in many ways. It is important that all engineers understand and utilise their ethical responsibility in the engineering practice. Engineers Australia provide a formal Code of Ethics for their members. This code provides an ethical framework and defines the values that shape the decisions engineers make in the industry (EA 2019). Without appropriate guidelines, dire consequences and implications may arise during an engineer's professional work life.

It is important that all engineers demonstrate integrity throughout their professional work life. Without respect and honestly, the world could not function safely. During this dissertation, I will aim to apply my knowledge and skills without bias and act in a professional manner. This dissertation involves various professional engineers from different backgrounds. It is important that I respect the dignity of all persons involved. As an engineer, I have an ethical responsibility to respect confidentiality especially when it comes to the literature review. I will ensure to give proper credit and reference the material as required.

To practise competently means to maintain and develop knowledge and skills. Engineers need to continue to develop their expertise and professional development due to the everchanging world around us. During this dissertation, I will aim to act on the basis of adequate knowledge. I will ensure my research is relevant to both the thesis and as a professional engineer. It will require me to examine the legal and statutory requirements as this thesis will encounter safety concerns.

Engineers are known to be trustworthy and have a high reputation in society. It is important that engineers make communicating with others a high priority. During this dissertation, I will be involved with various professional engineers that are currently in the industry. It is important that I communicate effectively and show a basis of leadership. As this is my personal dissertation, I must engage responsibly and advocate professional leadership.

Promoting sustainability and the environmental is a great responsibility for all engineers. There needs to be a balance established during this project to account for the present and future needs of the community. By considering the health and safety aspects of this product, it will provide a basis of the success of the design.

To become a successful professional engineer, these ethical standards and requirements must be followed throughout their professional life.

5. Project Methodology

This chapter intended to provide an overview of the methodology for this project. The project methodology explored the body of practices, procedures, and rules for the investigation. This section explained the type of research conducted, how it was analysed, and any tools used in the research. It explored the design development, desktop analysis, and design finalisation stages of the project. These sections will lead up to the results provided and discussed in the following chapter.

Once satisfied with the extent of the literature review, a desktop analysis was developed. This analysis provided an understanding of the structural capability of the designed systems. This desktop analysis aimed to consider different various thicknesses for the system, component material sizes, bonding effects, deflection, and cost. This data assessed the performance of each innovative building system compared with the corresponding cost. This provided options that give the best theoretical 'bang for buck' design.

Testing was the next stage of development completed at the USQ laboratory in early July. The physical testing aimed to assess the bending performance of the system. This was completed simulating real world UDL and PL as per the Australian loading code AS1170.2. This physical data was compared with the theoretical data regarding deflection and ultimate failures. This process provided an opportunity to develop structural span tables for the system. The physical testing provided a greater understanding of the factors involved, their importance and optimised solutions.

The theoretical analysis was validated with the empirical techniques performed during the testing stage. This provided a solution scheme. This scheme aimed to evaluate, calibrate, validate, and optimise the final design for the flooring system.

All phases were performed under the Australian Standards (AS) and the National Construction Code (NCC).

Applying innovative methods was a key factor throughout this methodology.

5.1 Development Process

5.1.1 Concept Development

5.1.1.1 Background

This thesis aimed to provide a step-by-step development process for an Australian innovative building system. It explored the planning, design, patenting, development, testing, manufacturing, distribution arrangements and marketing strategies for an innovative flooring system.

This development process aimed to answer the following questions through research and testing. What is the purpose for this flooring system? Why is it needed in the industry? What new aspects does it bring to the industry? Who does it benefit?

These questions were reviewed throughout this thesis to ensure the project is on the right track. It was important to answer each of these questions through research and testing as it increased the likelihood of a successful building product.

5.1.1.2 Purpose

The purpose for this innovative floor plank was to provide the domestic housing and light industrial market with an alternative flooring system. This building system is an alternative to the traditional timber bearer and joist flooring system. Currently, builders are dealing with long leads times for structural and LVL timber due to the high demand and limited alternatives available. The traditional bearer and joist flooring system is very labour intensive. Introducing this new flooring system to the construction industry will help reduce construction time and the raw materials being used during construction.

The traditional flooring system is made up of timber or steel bearer, joists, particle board flooring or often compressed sheet in wet areas. The traditional bearer and joist flooring system is becoming more economical than a concrete slab when building on a steeply sloping or uneven block. The traditional bearer and joist flooring system is also used in multi-storey single residential construction and light industrial mezzanine flooring. It is important to note that timber bearers are heavy and prone to warping over time. Figure 10 show the traditional bearer and joist set out plan displaying all the materials and steps needed to complete the job. Concrete piers, bearers, joists, trimmers, and blockings are all necessary materials.

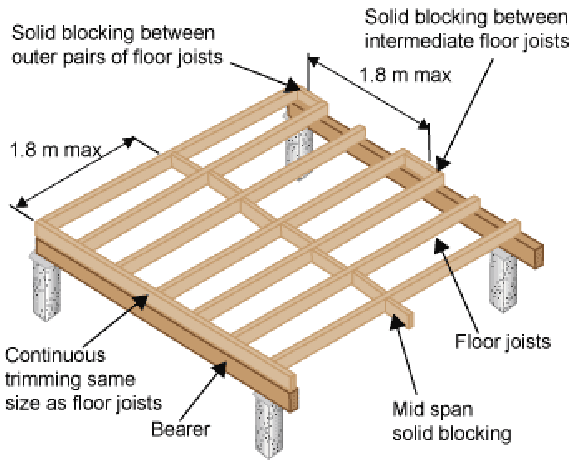


Figure 10 - Traditional Bearer and Joist Set Out

This project aimed to create and highlight a gap in the market with an opportunity to improve construction methods. This alternative flooring system has the potential to save both time and money for developers, builders, and the homeowner. These laminated floor planks are a lightweight alternative, with less components, that will assist in a faster and safer installation.

This system is suitable for low set timber flooring, houses on sloping sites, two storey developments, mezzanine light industrial designs and relocatable buildings. This alternative flooring system provides opportunities for less raw materials to be used during construction, with minimal skills required for installation. Overall, this floor plank has the potential to benefit builders due to reduced time, cost and skills required.

5.1.2 Feasibility Study

5.1.2.1 Costing Exercise

A costing exercise was completed to estimate the building costs per square metre for the traditional bearer and joist flooring system. This provided an average cost range based on the Rawlinsons Australian Construction Handbook 2020, edition 38*. The local Brisbane prices were used for this exercise. A costing exercise assisted in answering whether this innovative flooring system will be a viable alternative to the traditional bearer and joist flooring system.

The average QLD house as of 2020 is 228 m^2. A simple 4-bedroom, 2-bathroom stumped house was used for the preliminary costing exercise, shown in figure 11.

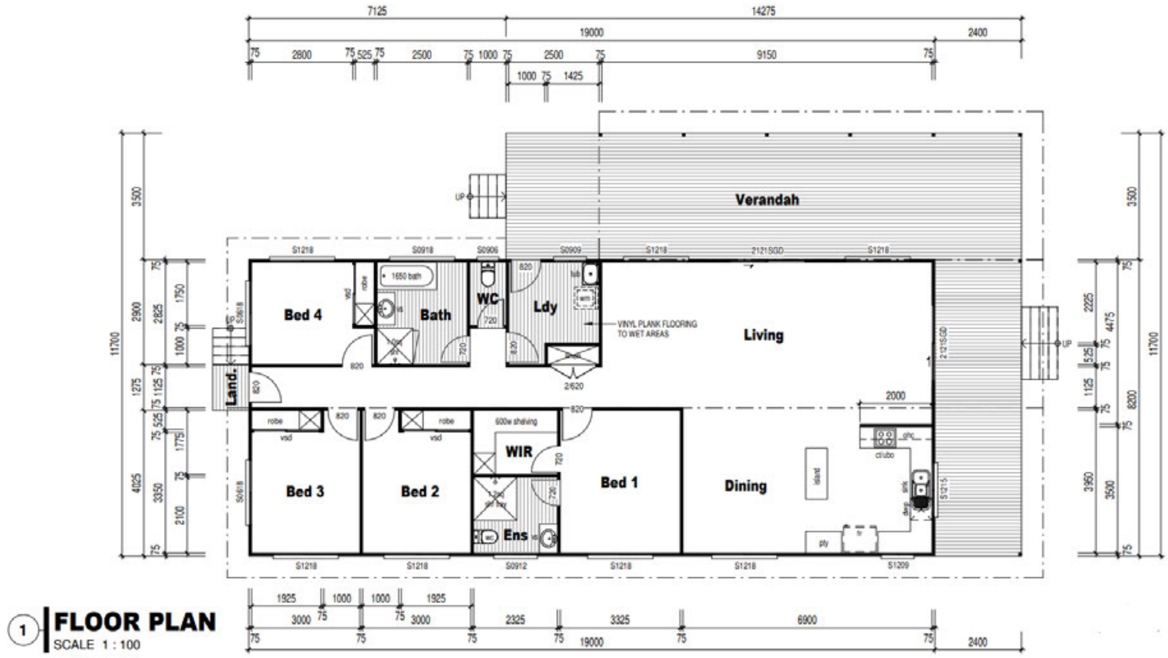


Figure 11 - Prelim House Floor Plan

This is a single storey stumped weatherboard home situated on a sloping block in Brisbane. Local hardwood green sawn timber with a stress grading of F14 was considered for the foundations, wall, and roof framing. 35 adjustable steel stumps will be used. Medium level of finishes was considered.

Material	Timber Size	Centres	$ / m² *	Project Cost
Bearer	150 mm x 75 mm	1800 mm	$26.70	$6,087.60
Joists	100 mm x 50 mm	450 mm	$54.70	$12,471.60
Subfloor Fixings	-	1800 mm	$12.00	$2,736.00
Wall Framing	90 mm x 45 mm	450 mm	$63.70	$14,523.60
Roof Framing	100 mm x 50 mm	900 mm	$4.65	$1,059.09
Finishes	-	-	$36.00	$8,208.00
Landscaping	-	-	$55.00	$12,540.00
Labour	-	-	$1,300.00	$296,400.00
Extras	-	-	$1,000.00	$228,000.00
Total			$2,625.00	$598,500.00

For the preliminary feasibility purpose, a number of building assumptions were used. Further investigation into the costing of insulation, floor coverings, and finishes would be required to achieve a more exact costing solution.

5.1.2.2 Market

The literature review explored some innovative building systems being used in today's building industry. Most of the successful innovative panels have been designed as sandwich panels. Allen (1969) describes the typical building sandwich panel layout to comprise of two strong, thin sheets of dense material which are separated by a thicker core material which generally has a lower density.

Some alternative systems have been successful in entering the Australia building industry. Researching the current building market provided a record on the important advantages an innovative building system should incorporate in the final design.

- Lightweight and rigid
- Insulation against heat, cold, humidity, and sound
- Reduced transport speed and ease of installation
- Reduced labour time and cost
- Safe and efficient

Recent trends in the construction industry have given opportunities to expand on the sandwich panel concept. Market acceptance for innovative flooring systems has been deemed difficult due to tighter building safety standards and the lack of appropriate guidelines. The NCC provides a uniform set of regulations designed to establish essential construction standards for structural adequacy, fire resistance, and public health for an innovative flooring system (NCC 2021). New building systems must demonstrate compliance to allow product acceptance through the NCC. The design process is an iterative procedure for all flooring structures that must satisfy the pathway set out in the NCC. The current NCC only provides designers with general information exploring the relevant issues and standards to be considered when planning and designing an innovative flooring system. This could be a reason why innovative flooring systems entering the Australian building industry is deemed difficult. The NCC defines the function of the footing is not only to distribute vertical loads from the building to the foundation, but to ensure that the building superstructure performs satisfactorily (NCC 2021). This home renovation boom causing long lead times for structural timber could force the Australian building industry to think differently when it comes to building alternatives. This may be an opportunity for developers of innovative building systems to gain some market acceptance in the residential building industry that is normally very slow to adopt new systems. Increasing innovative product market acceptance and adoption is the first step for product acceptance.

It is important to research the current building alternatives being used in Australia as it provided the building developer with an understanding on the current building market.

5.1.2.3 Laws and Regulations

Expanded Polystyrene (EPS) is being used in today's building industry as it is lightweight, strong, durable, moisture resistant, thermal efficient, shock absorption, and versatile. EPS is known to outlast other building materials as it does not rot and does not attract pests.

The literature review explored the safety issues, fire performance, toxicity issue and additives for EPS. It was found that fire safety is one of the essential requirements when designing a residential and light industrial building in Australia. EPS is an organic material that is combustible. Most EPS products have been made of fire retarded quality, by adding a fire-retardant agent to the material. EPS is best suited when insulated and sandwiched between two facings. An EPS core is an option to consider when designing EPS planks.

It is important that all construction products abide by the standards and code set by the specific country. Australian Standards are published documents with a set of specifications and procedures that have been designed to ensure safety and reliability. The National Construction Code (NCC) provides the minimum requirements for safety, health, and sustainability for innovative building systems. By following these Australian codes, it will ensure this building system is safe and reliable for future construction.

5.1.2.4 Safety Procedures

Safety procedures are standardised work processes that help minimise risks in the workplace. 'Safe Work Australia' is an Australian Government statutory agency that have developed standard safety procedures for the building industry.

These developed documents provide guidance on managing risks with safe work methods and WHS management plans. Throughout this thesis, the 'Code of Practice' documents have been researched and followed to ensure a safe environment and safety of the system.

5.1.3 Patenting

5.1.3.1 Overview

New building systems need to have an 'innovative step' to be patented. It is important for all new systems to identify the importance of patenting during the development stage. Patents protect the cost of development of the product or building system for a period of time. This way the developer has time to become established in the target market and recoup development costs. Once this period of time expires, the competitors are allowed to copy the product or building system and compete with the original developer (IP Australia 2014).

An Australian Innovative Patent is designed to protect inventions that do not meet the inventive threshold required for standard patents. A patent claim is certified through the *Patents Act 1990* and lasts up to eight years (IP Australia 2014). This innovative building system will need to have at least one 'innovative step' that makes a substantial contribution to the working of the invention.

5.1.3.2 Guidelines

The Australian Government IP Australia have outlined the requirements for obtaining an innovative patent in Australia (IP Australia 2014).

1. The innovation is a patentable subject matter – this flooring system is a manufacturing process.
2. The innovation is new (novelty) – this flooring system needs to be new to the world. Must not have been made public prior to claim.
3. The innovation is inventive – needs to have an 'innovative step' or solution. Must not be obvious to a manufacturer otherwise it is not inventive.
4. The innovation is useful (utility) – relates to the industrial applicability. Whether the product is capable of being manufactured, sold, and distributed.
5. The innovation must not have prior use – the product must be new to the economy and unlicenced.

When applying for an innovative patent, the specifications must fully describe the innovation, clearly define the claim, and can include the use of drawings where applicable. The innovative patent claim must comply with legislative requirements through the *Patent Act 1990*.

5.1.3.3 Steps

This innovative building system has not been established in the construction industry. This system involves the exploitation of a new system. Therefore, an innovative patent claim is necessary to protect the cost of development. A provisional patent application was completed during the development process for this innovative building system. The following steps were taken to ensure this building system is protected.

- The first step in the patenting process is to develop a set of conceptual drawings. These drawings are developed by the patent attorney. At this stage of the process, the purpose, components, and configurations are developed as the illustrated drawings are developed. The descriptions must have enough clear detail so that someone with knowledge of the technology could reproduce your invention from the information given. Product variables are also considered during this stage.
- This innovative patent application allows up to five claims to be made at once. This is developed alongside the patent attorney. These claims need to describe the innovative product. The products components, fixings, application, and methodology are assessed. More detailed claims provide a greater chance for protection. This stage is constantly reassessed to ensure the claims being made involve an innovative step.
- The drafted application is sent to all parties to check it satisfies formalities. This step is important as once the provisional specifications are established, new designs are unable to be added to the application. This process can be tedious as all parties involved must be satisfied before continuing to the next patent step.
- The provisional application is then lodged. The date when the patent application is lodged is known as a “priority date”. This is an important concept for all parties to understand as it immediately protects the product and its development.
- The patent attorney examines the claim by investigating products from around the world. It is common that the patent claim is returned with reduced claims after investigation. It is important that all parties involved understand that publication is an important step. Once granted, the innovation patent is no longer confidential and is published.

This is a long process as the products claims generally alter and change as time progresses. This is a work in progress as the product or system usually requires iterations of trial and error, refinement, and development.

Funding is a large part of this patent claim. Since the process is long and tedious, there is a big cost to the developer of the building system throughout this process.

5.1.3.4 Commercial in Confidence

The concept of confidentiality is vital when it comes to processing a new product under the *Right to Information Act 2009 (RTI Act)*. Since this innovative building system is still being finalised, the concepts being tested are sensitive. The building developer must take the necessary steps to protect the systems information.

Commercial in Confidence means the people receiving this information are obligated to not disclose the product without consent. This type of information is typically protected through confidentiality agreements. A non-disclosure agreement was signed at the beginning of this research topic to protect both the building developer and the innovative system. This legal framework was used to protect the sensitive and confidential information of the product.

Written approval has been received for this dissertation to remain confidential after the assessment processes are completes. In other words, this innovative building system is legally not for distribution.

5.1.4 Design and Development Planning

5.1.4.1 Overview

Design development is the process of creating new knowledge about a product. A product innovation has been used to describe a breakthrough in development. During this stage of development, formal plans are established with labelled explanations. In this case, this occurs in conjunction with the patenting process.

This section explored the list of components and materials needed to produce the system. This included the core material EPS, F11 timber stringers, and 5 mm sheet metal. Environmentally friendly alternatives will be considered and assessed.

5.1.4.2 Components

Expanded Polystyrene (EPS) is a closed cell structure produced from polystyrene (AUS 2011). EPS provides moisture resistance, thermal efficient and shock absorption as a building material. Over the years, the material has been developed and modified by the addition of flame retardant additives. The manufacturing process involved pre-expansion, aging, moulding, drying, and finishing. It was found in the literature review that EPS has its own Australian Standard that explores the physical properties of EPS; AS1366.3 – Physical Properties of Rigid Cellular Polystyrene. This code sets out the minimum properties for each class of EPS. The physical properties of EPS have a range of classes and properties for different purposes. In Australia, insulated panels typically use an SL grade of EPS, which has a nominal density of 13.5 kg/m^3. This project will follow this guideline. Expanded Polystyrene was chosen as the core material in this flooring system due to its strong and durable nature, lightweight structure, and insulating aspects. Being an environmentally friendly alternative will increase the products chance for acceptance and adoption.

Figure 12 - EPS Building Material
https://www.thefoamcompany.com.au/collections/construction-packaging-industrial

The timber stringers were designed to give the top sheet metal something to bond to. Treated pine provides a durable and strong connection method. The four strips of timber still allow the plank to be lightweight for manufacturing and installation purposes. Timber is such a diverse building material that over time has been sorted and tested into appropriate stress groups. Stress grades are derived from visual or machine grading, which specifies the stress limits that apply to timbers being used for structural applications. AS1720.1 – Timber Structures outline the requirements for each group. When designing this building system, it is important to consider the benefits of each timber grade. Table 5 outlines the characteristic values for structural design for various F-grade classifications of structural plywood. After careful consideration, an F11 grade structural timber has been chosen for the design of the innovative building systems. This F11 structural timber kind provides a working stress in bending of around 11 MPa. The chosen timber is a high strength timber that is ideal for frames, walls, floor joists and supports in a residential building.

TABLE 5.1

STRUCTURAL PLYWOOD — CHARACTERISTIC VALUES FOR F-GRADES
(Moisture content 15% or less)

Stress Grade	Characteristic values, MPa						
	Bending (f'_b)	Tension (f'_t)	Panel shear (f'_s)	Compression in the plane of the sheet (f'_c)	Bearing normal to the plane of the sheet (f'_p)	Short duration average modulus of elasticity MPa (E)	Short duration average modulus of rigidity MPa (G)
F34	90	54	6.0	68	31	21 500	1 075
F27	70	45	6.0	55	27	18 500	925
F22	60	36	6.0	45	23	16 000	800
F17	45	27	6.0	36	20	14 000	700
F14	36	22	5.5	27	15	12 000	625
F11	31	18	5.0	22	12	10 500	525
F8	25	15	4.5	20	9.7	9 100	455
F7	20	12	4.2	15	7.7	7 900	345

Table 13 - Structural Plywood Characteristics

Due to the current shortages of treated hardwood, possible variations may need to be explored to ensure the continuation of development for the product. These variations may include the size, type, and stress grade of the timber stringers.

Sheet metal is a lightweight construction material that provides options in different sheet thicknesses. Sheet metal is a low maintenance product that has a high resistance to differing weather conditions. This gives a durable wrapped product that protects the centre materials. This cladding provides for a range of styles and finishes, which could be explored further in the development stage of this flooring product.

Gauge	Thickness	Weight
	mm	kg/m²
3	6.07	47.62
4	5.70	44.66
5	5.31	41.67
6	4.94	38.70
8	4.18	32.75
10	3.42	26.79
12	2.66	20.83
14	1.90	14.88
16	1.52	11.91
18	1.21	9.52
20	0.91	7.15
25	0.53	4.16
30	0.31	2.39
35	0.19	1.49

Table 14 - Sheet Metal Gauge Size Chart

5.1.4.3 Variables

The panel dimension may be altered during the design and development stages of this process. It is important to explore the spanning capacities while aiming to keep the plank thickness to a minimum. This will be initially explored in the desktop analysis and validated during the testing phase. Once the plank performance is assessed, variations of thicknesses will be explored with relation to the overall costing. It is important for any building product to provide the best "bang for buck" outcome.

EPS provides different class foams which differ in nominal density. Density represents the compactness of the building material. During the initial design and testing stages, a SL grade of EPS was adopted, which has a nominal density of 13.5 kg/m^3. This follows the minimum requirements set out in AS1366.3. Once the performance of the plank has been tested, different densities may be explored if necessary.

Timber stringers provide a bonding effect on the plank. Without proper bonding of materials, the strength and capacity will be greatly affected. For testing purposes of the plank, a 90x45 mm treated pine was used. Timber is available in a number of lengths and thicknesses that come at different costs. This material has the potential to change throughout the testing period to ensure the best outcome is achieved.

Sheet metal is available in different types, thicknesses, and gauges. For testing purposes of the plank, a 6 mm sheet metal was used. It is important in building design to consider the most economical product without impacting the safety of the product.

It is important that today's building materials are environmentally friendly that provide possibilities for recyclability. During the research stage of this product, environmentally friendly alternatives for the above chosen materials will be assessed and explored.

5.1.5 Manufacture

5.1.5.1 Overview

All product developers must consider market entry and manufacturing techniques. This section will consider the overall costing of the building systems, known as a costing exercise, possible marketing strategies, storage opportunities, the best suited distribution strategy, and installation possibilities.

5.1.5.2 Costing

Building Solutions Pty Ltd have established a trade price of $204 per square metre for the plank. For preliminary purposes, this is the plank price charged to a manufacturer. This innovative flooring system was documented to be a viable alternative to the traditional bearer and joist flooring system. The manufactured plank reduced the need for HWD bearers, while provides a greater strength than HWD joists. Research and testing found a comparison in Tilling Timbers 'Smart Floor' cassette system.

Building Solutions Pty Ltd have established a trade price of $60 per metre for the beam. After research and testing, it was found that this beam is higher in strength and shear capacity when compared with standard structural timber. The engineered wood product from Smart Frame, Laminated Veneer Lumber (LVL) is the closest comparison in function. To achieve the same strength and capacity, 2 glued 140x56 Smart LVL 15 would need to be used, with a retail price of $58 per metre. It is evident that our innovative beam design is competitive in cost.

5.1.5.3 Marketing

During production, every product and system needs to have a plan to ensure the success of the item. This innovative building system will aim to provide a large enough profit margin to allow for a license IP. A license IP is an entered legal agreement that allow for a distribution banner (IP Australia 2014).

This systems founder has been in contact with a number of construction enterprises that supply marketing and distribution opportunities. Arc Panel and Ritek are companies that manufacture, market, and distribute building systems through their own platform.

If this flooring system expands, the opportunity for retailers like Bunnings and Mitre 10 will allow for future sales and distribution. However, the profit margin grows exponentially once external enterprises are introduced.

If this building system enters this process, it is important to be conscious of the profit margins as it will need to accommodate for every party involved. All parties need to have motivation to manufacture, market, sell and service customers to ensure the product will succeed in the industry.

5.1.5.4 Suppliers and Storage

It would be most acceptable to sell the planks and beams through standard sizes at multiples of 300 mm, like the timber joist distribution. This provides customers with immediate products that can be easily pulled out of stock and bought off the shelf. This eliminates the design process and provides a cheaper system for all parties. To ensure this suppling is possible, options to cut the plank and beam need to be considered.

The alternative flooring system will be designed to be stackable for storage requirements. This will allow manufacturing workshops to prefabricate a mass production line whilst not affecting the product space.

5.1.5.5 Distribution and Delivery

It is important to consider the distribution opportunities for the building systems during the development process. Similar to the marketing possibilities, securing a licences manufacturer and distributer provides opening for one profit margin. Once two or more enterprises are introduced, the profit margin grows exponentially. Licenced manufacturers have an established distribution network that suit the current market. It is important to consider manufacturers who have a diverse range of buyers. This allows growing possibilities for the product. Australian Timber and Trusses Pty Ltd are an Australian company that supply fabricated products to the building industry. This company is a licenced building manufacturer who distributes to a wide range of customers from homeowners to national builders.

5.1.5.6 Installation

Installation techniques and handling will aim to be investigated during the testing stages if time permits. The design of this flooring system has considered the ease of installation by considering the weight of the panel, the fitting techniques, and floor coverings. These techniques have been compared with the existing bearer and joist flooring system to ensure a competitive market.

5.1.6 Testing and Validation

5.1.6.1 Overview

For the testing purpose, 3 planks and 2 beams were fabricated and manufactured. Due to the scope of works, only one floor plank and beam was documented. Each manufactured building system had a different configuration. The floor plank and beam with the EPS core was documented and validated.

This is the stage where the theoretical calculations undertaken in the desktop analysis aimed to be validated. Once the testing of the building system is complete, verification of the function and performance was finalised.

5.1.6.2 Techniques

The testing stage aimed to replicate the typical uniformly distributed load (UDL) and point load (PL) outlined in the building code AS1170.2. These testing techniques aimed to verify the performance capability of the flooring system.

If time permits, various configurations, materials, and bonding techniques like double sided tape, glue, nails, etc, was hoped to be considered and compared with the requirements for the flooring system. The initial testing stage assessed the chosen material variation and evaluated any potential risks that might be recognised.

5.1.6.3 Performance Requirements

During the desktop analysis, a set of structural requirements were developed. These requirements were established in conjunction with the Australian Standards (AS) and the National Construction Code (NCC). These Australian codes provide the minimum requirements for safety, health, and sustainability for innovative building systems. Following these codes ensure this building system is safe and reliable for future construction.

5.2 NCC Pathways

The National Construction Code supplies information on ensuring a building product or system is safe and fit for purpose. The NCC refers closely to the relevant Australian Standards for each section. For the purpose of this research topic, residential construction will be the main focus of compliance. Volume 2 Part A2 of the code outlines various compliance pathways within the NCC. New building systems must demonstrate compliance to allow product acceptance through the NCC (ABCB 2019).

For a building system to comply with the NCC, a solution must achieve compliance with the Governing Requirements and Performance Requirements. Performance Requirements are the only NCC technical provisions that must be satisfied, by one of the following.

1. A Performance Solution: This can be achieved by demonstrating compliance with the relevant performance requirements through Assessment Methods (evidence of suitability, verification method, expert judgement, or comparison with method two).
2. A Deemed-to-Satisfy Solution: This is achieved where an acceptable construction manual or construction practice demonstrates compliance with the relevant performance requirements through Assessment Methods (evidence of suitability, or expert judgement).
3. A Combination of (1) and (2): This can be achieved by identifying both the relevant Deemed-to-Satisfy provisions and the relevant performance requirements.

Whichever method is chosen for compliance, building systems must always meet the Performance Requirements of the NCC.

In Australia, a form 15 assures that a building system complies with the relevant regulations. The aim for this flooring system is to have a qualified certifier inspect the system and sign off on its capability. To achieve this certification and satisfy the form 15 requirements, the strength, deflection, and span capacities need to be demonstrated. This is done by testing the system and proving its ability to perform under load.

Research has shown that combustible materials prove to be a grey area that is yet to conform with the NCC. The fire resistance level is not required for small residential constructions (ABCB 2019). The compliance pathways within the NCC could be challenging to follow if a difference building class is adopted for this flooring system. Entering the commercial, industrial, and even multiple residential markets pose the fire rating conformity issue that would need further documentation and investigation.

5.3 Expected Project Outcomes

5.3.1 Concept Development

The concept stage of this design considered the operational needs and requirements for an innovative flooring system in Australia's construction industry. The construction industry consists of poor productivity, design complexity, sustainability concerns, and skilled labour shortages. The aim of the concept design was to achieve each of these building problems.

Construction productivity has remained constant for decades. For example, the traditional bearer and joist flooring system requires extensive design steps to ensure the most efficient and economical design. Timber selection, member design, fixings, bracing, installation, finishing's, and maintenance are the typical steps that need to be followed as per the National Construction Code.

Sustainability in construction has become a key factor for the successful completion of construction projects. The rising attention to environmental issues from the government and the public has forced builders to incorporate sustainable criteria when planning and completing project. Sustainability in construction is currently focussed on the design aspects and raw materials used in buildings. It is important that building system developers must actively react in a positive manner to environmental issues. 6 main principles of sustainable construction were considered throughout the development of the innovative building system.

- Maximisation of resource use
- Minimisation of resource consumption
- Use of renewable and recyclable resources
- Protection of the natural environment
- Creation of a healthy environment
- Creation of quality in built environments

Labour and material shortages can be the catalyst for new building systems to be accepted, as this may force builders to think differently.

The concept stage of this design considered the key questioning strategies: "who, what, where, when, why, and how". These questions address system flaws and gaps, constraints, and product limitations. The aim of this concept design is to develop a building system that closes the gap. Below are a range of concept sketches that have been developed and analysed. Some of these designs have reached the testing stages but are out of this scope of works.

5.3.2 Project Schedule

A timeline was development at the beginning of the academic year to ensure that the project objectives will be achieved within the desired timeframes. Project milestones and deadlines were established. The project began in February and was finalised in October. The key project tasks are summarised below:

- Initial Documentation: once the research topic was accepted and finalised, the statement of aims and objectives, background information, and project scope was developed for the dissertation. This was discussed regularly and frequently sourced back to ensure the project is on the right track.
- Literature Review: this stage provided an in-depth investigation into the traditional bearer and joist flooring system, and how this system can be developed to suit the everchanging building industry. Current Australian building alternatives were assessed. This is the stage where research into EPS was critical.
- Project Outcomes: this stage was researched and revised throughout the dissertation. Structural analysis was completed before and after the physical testing was completed, which assisted in the final design documentation. Innovative building pathway through NCC was a critical research topic that provided the team with valuable industry information.
- Methodology: this stage explored the body of practices, procedures, and rules for the investigation. At this stage of the project, the methodology was finalised.
- Development Process: this project aimed to provide a step-by-step development process for an Australian innovative building system. This section explored the planning, design, patenting, development, testing, manufacturing, distribution arrangements and marketing strategies for an innovative flooring system. This stage answered the project feasibility questions.

- Risk Assessment: this project aimed to identify hazards and risk factors that have a potential to cause harm to individuals and the environment. Appropriate mitigation techniques relating to the personal and project risks were explored to minimise the impact of these risks.
- Resource Planning: it is important to plan the appropriate resources throughout this project to ensure it runs smoothly and the timeline won't fall behind. Materials, testing, and documentation are all resources that were identified.
- Testing: testing aimed to assess the bending performance of the floor plank and beam systems. The testing stage validated the desktop analysis.
- Documentation: once testing is complete, appropriate conclusions and alterations were made to the innovative systems. To ensure adequate time for documentation, manufacturing of the products and testing was completed in early July.

Refer to section 8 for the detailed project schedule.

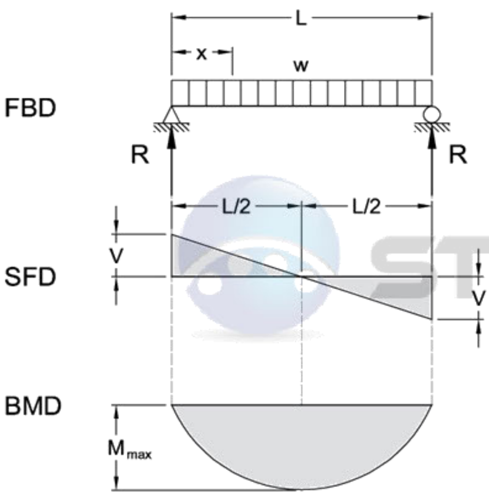
5.4 Desktop Analysis

A desktop was developed to help understand and comprehend the design of the plank and beam. An initial analysis was developed to determine how well the systems will perform under load. This theoretical analysis was compared with the results from the testing stage.

Throughout the development stages, this desktop analysis was updated and improved to satisfy the changing needs of the system.

5.4.1 Plank

The manual calculations for the plank considered UDL on a simply supported plank. The appropriate equations for the reaction forces, maximum moment, and maximum deflection are shown below.



$$R = V_{MAX} = \frac{wL}{2}$$

$$V_x = w\left(\frac{L}{2} - x\right)$$

$$M_{max} \text{ (at centre)} = \frac{wL^2}{8}$$

$$M_x = \frac{wx}{2}(L - x)$$

$$\Delta_{max} \text{ (at centre)} = \frac{5wL^4}{384EI}$$

$$\Delta_x = \frac{wx}{24EI}(L^3 - 2Lx^2 + x^3)$$

Figure 13 - Simply Supported Beam with UDL
https://structx.com/Beam_Formulas_001.html

A set of potential plank thicknesses were chosen, ranging from 40 mm to 200 mm. The corresponding deflection in mm was calculated for each plank thickness. The deflections were validated using the standard load in AS1170.1. A preliminary costing exercise was then completed to comprehend what the best 'bang for buck' plank design will be, shown in table 7. The two following graphs were created for analysis.

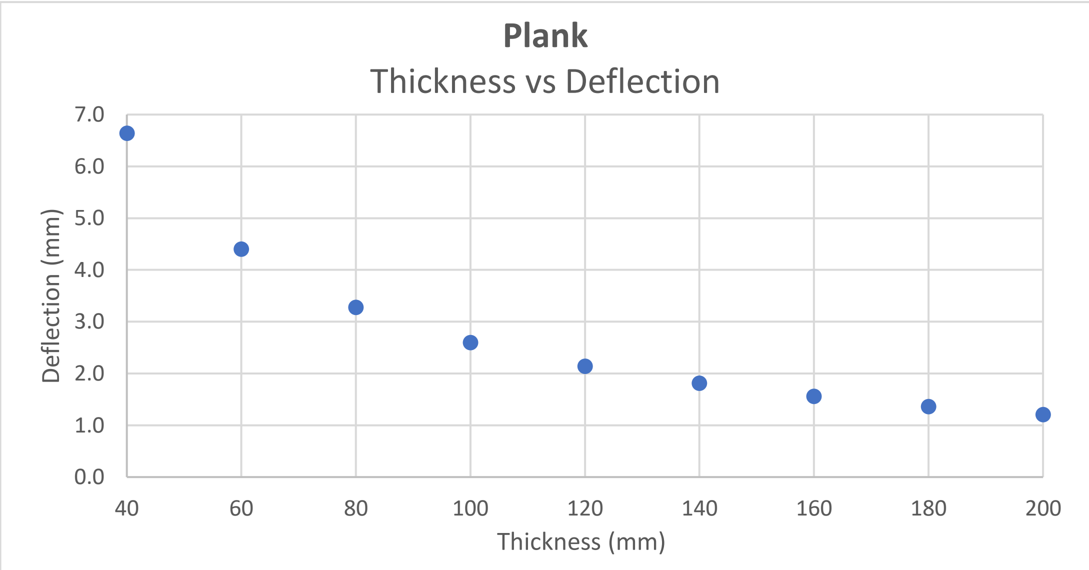
- Thickness (mm) vs Deflection (mm) -> graph 1 and graph 3
- Thickness (mm) vs Cost ($) -> graph 2 and graph 4

Plank Dimensions			
Span	L	4800	mm
Width	W	600	mm
Applied Force	F	4	kN/m
Deflection Limit	L/300	12	mm

Thickness (mm)	Deflection (mm)	Cost ($)
40	6.64	$97.01
60	4.40	$119.73
80	3.28	$143.30
100	2.59	$168.24
120	2.14	$195.34
140	1.81	$225.86
160	1.56	$261.80
180	1.36	$306.33
200	1.20	$364.48

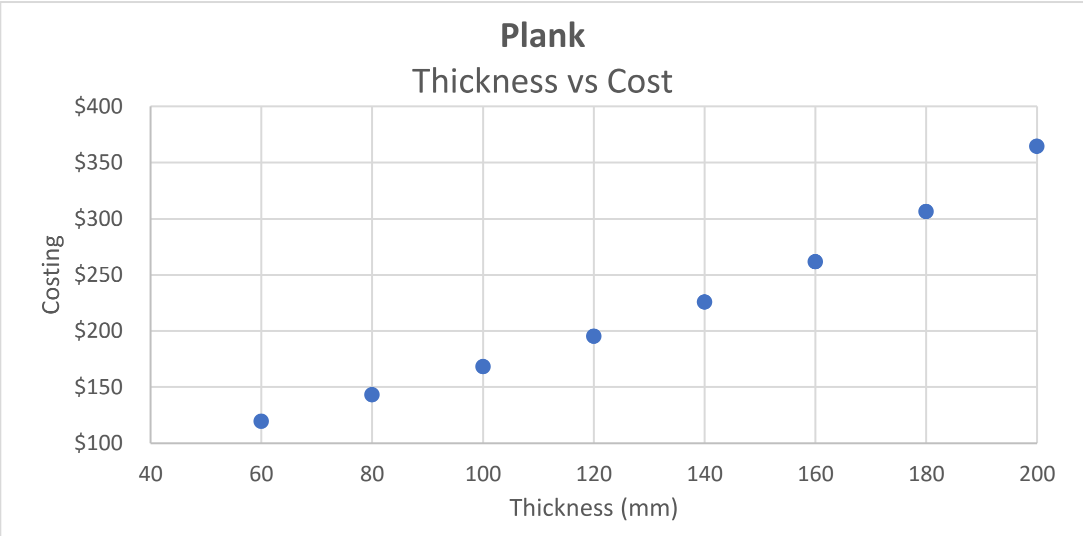
Table 15 - Plank Analysis

A chosen span length of 4.8 metres and plank width of 0.6 metres was chosen for analysis. This is a typical spanning length for other subfloor designs. A 4 kN/m constant force was applied to the manual plank calculations as per the Australian loading code for residential flooring. The manual calculations proved all plank thicknesses are within the deflection limits set out in AS1170.1. This will need to be validated through physical testing.



Graph 1 - Thickness vs Deflection (Plank)

Graph 1 shows a steady decline in deflection as the planks are made thicker. This was predicted in the initial evaluation. As the manufactured plank thickness increases, the graph has a continuous gradual decline. The maximum allowable deflection for a floor plank set out in AS1170.1 needs to be carefully considered.

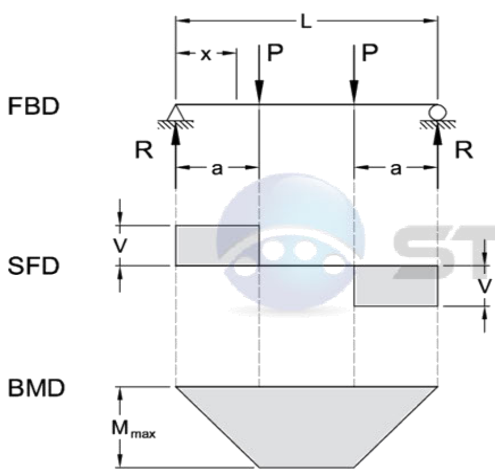


Graph 2 - Thickness vs Cost (Plank)

Graph 2 shows a steady incline in costing as the floor plank thickness increases. was predicted as the volume of materials and labour increase. If the calculated were continued past a 200 mm plank thickness, it can be predicted that the price will have a steeper increase. Based on the manual calculations and this costing exercise, the best 'bang for buck' design would be to manufacture a 140 mm thick plank. Further investigation into the loading capabilities and manufacturing costs for each plank thickness should be performed.

5.4.2 Beam

The manual calculations for the plank considered two equally spaced point loads on a simply supported beam. The appropriate equations for the reaction forces, maximum moment, and maximum deflection are shown below.



$$R = V \ldots = P$$

$$M_{max} \text{ (between loads)} \ldots = Pa$$

$$M_x \ (x < a) \ldots = Px$$

$$\Delta_{max} \text{ (at centre)} \ldots = \frac{Pa}{24EI}(3L^2 - 4a^2)$$

$$\Delta_x \ (x < a) \ldots = \frac{Px}{6EI}(3La - 3a^2 - x^2)$$

$$\Delta_x \ (a < x < (L - a)) \ldots = \frac{Pa}{6EI}(3Lx - 3x^2 - a^2)$$

Figure 14 - Simply Supported Beam with Two Equally Spaced Point Loads
https://structx.com/Beam_Formulas_009.html

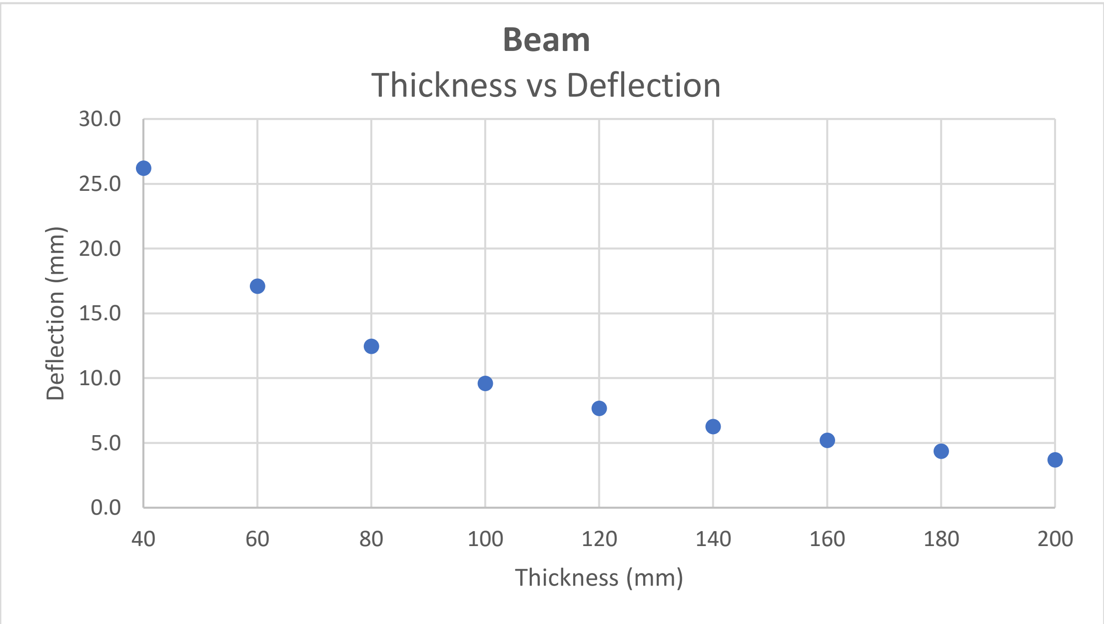
The same process was repeated for the design of the beam. A range of beam thicknesses were chosen, the corresponding deflections were calculated, and the associated costs were estimated, as shown in table 8.

Beam Dimensions			
Span	L	4800	mm
Width	W	300	mm
Applied Force	F	4.5	kN
Deflection Limit	L/300	10	mm

Thickness (mm)	Deflection (mm)	Cost ($)
40	26.20	$30.02
60	17.09	$36.72
80	12.45	$40.87
100	9.60	$49.56
120	7.66	$76.63
140	6.26	$119.19
160	5.19	$190.37
180	4.36	$314.42
200	3.69	$536.20

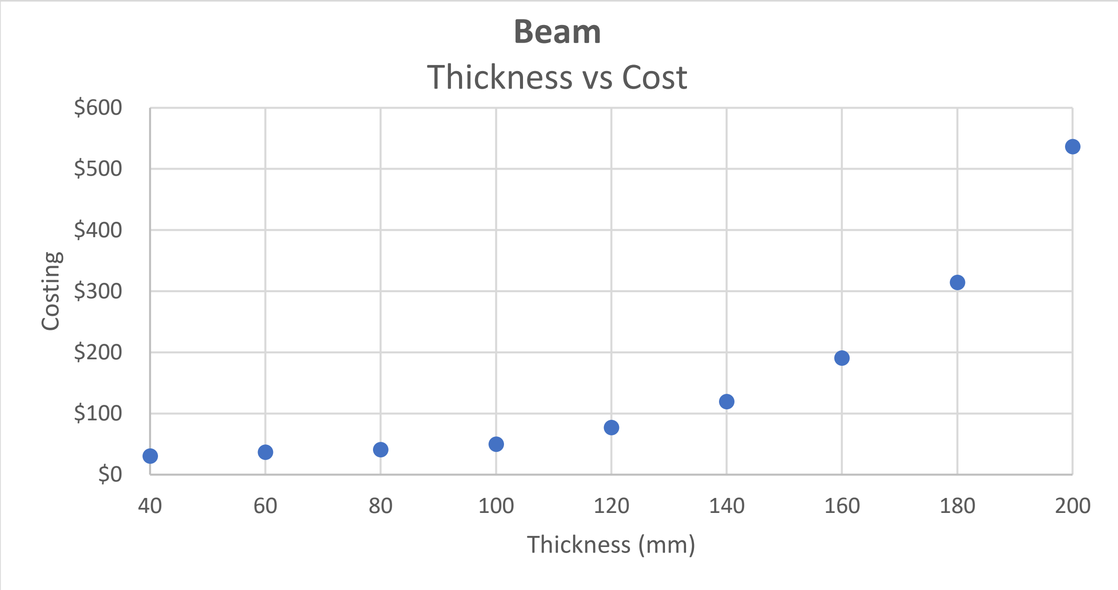
Table 16 - Beam Analysis

The same span length of 4.8 metres was chosen for the manufactured beam. The width of the manufactured beam was half that of the plank. A 4.5 kN constant force was applied to the beam calculations as per the Australian loading code for residential buildings. The manual calculations proved only the beams above 100 mm thickness are within the deflection limits set out in AS1170.1. It is evident that manufacturing a thinner beam will result a failure mode in deflection.



Graph 3 - Thickness vs Deflection (Beam)

Graph 3 shows a steady decline in deflection, similar to the plank. This was predicted in the initial evaluation. It is important to consider ensure the chosen manufactured beam thickness is within the deflection limits set out in AS1170.1. These limits are in place to minimise the possibility of damage to the material as well as provide a reasonable comfort for the building occupants.



Graph 4 - Thickness vs Cost (Beam)

Graph 4 shows a steady incline in costing as the beam thickness increases. Similar to the floor plank prediction, this was expected. Based on the manual calculations and this costing exercise, the most beneficial costing design would be to manufacture a 100 mm thick beam. Further investigation into the loading capabilities and manufacturing costs for each beam thickness should be performed.

In design, it is important to assess the performance of various thicknesses for a product. This provides the building developer with an understanding about how well the floor plank and beam will perform under load. All theoretical calculations were validated through physical testing. In addition, a preliminary costing analysis was performed on each of the innovative systems to provide the building developer the best 'bang for buck' design.

5.4.3 Final Design Development

All innovative building systems go through a pathway of acceptance by certifiers, engineers, and the building industry. During the development stages, it is important to research and understand what is required to create a successful building pathway. This ensured the innovative building system can be sold and used throughout the building industry.

Physical testing validated the theoretical design. Testing and design certifications needed to comply with the appropriate Australian Standards. Similarly, all building materials and methods need to comply with the National Construction Code. Once the building system was tested and validated, a test report was developed to assess the product against the criteria.

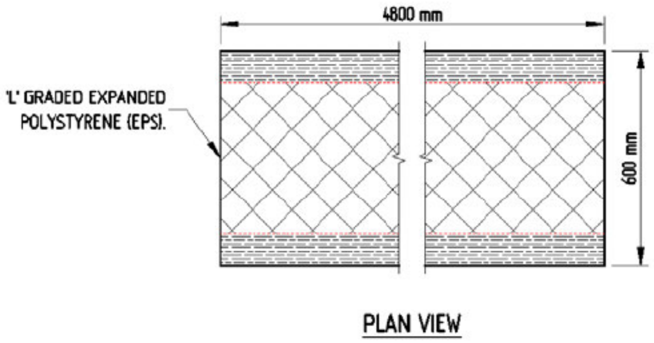


Figure 15 - Final Plank

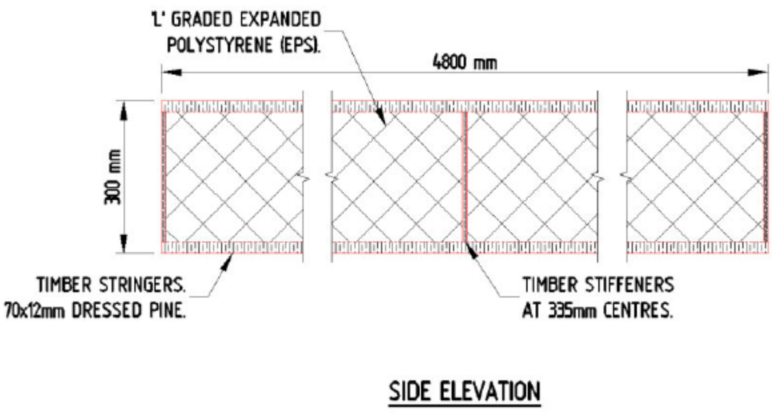


Figure 16 - Final Beam

5.4.4 Structural Design Actions

AS1170.0 – Structural Design Actions: General Principles provides designers with general procedures and criteria for the structural design of structures. It outlines a design methodology that is applied in accordance with established engineering principles. When designing a new building system in Australia, the following design actions must be considered:

- Permanent Action (dead load)
- Imposed Action (live load)
- Wind Actions

In Australia, a structure shall be designed and constructed in such a way that it will, during its design working life, with appropriate degrees of reliability sustain all actions and environmental influences likely to occur. The structural design must be carried out using the design procedures in the serviceability limit state and strength limit state.

The importance level of the innovative building system falls under category 1. The future structure presents a low degree of hazard to life and other property.

5.4.4.1 Serviceability Limit State

AS1170.0 provides the serviceability limit states to be used in checking the serviceability of a structural element. The serviceability limit state represents the criteria governing the design. It refers closely to the limits on acceptable performance for a beam. A number of appropriate combinations have been considered and are set out in AS1170.0 and can be seen in table 9.

Formula	Description
G	Permanent action only
$\psi_s Q$	Short-term and imposed action
$\psi_l Q$	Long-term imposed action
W_s	Wind action
E_{serv}	Earthquake action
Serviceability values of other actions	As appropriate

Table 17 - Serviceability Limit State Combinations

These combinations ensure all potential loading cases are considered during structural design. The limit state of serviceability combinations considers both short-term and long-term deflection limits.

Short-term deflection means the immediate deflection after applying the load. The magnitude and distribution of live loads, the type of end supports, and the span are factors that may influence the short-term deflection of a beam. A short-term factor Ψ_s of 0.7 is used. This factor is used to calculate the combination of actions for serviceability limit state.

$$Stability_{short} = G + \varphi_s Q$$

Long-term deflection occurs over a long period of time and is largely due to shrinkage and creep of the material. The temperature, type, and size of aggregates may influence the long-term deflection of a beam. This is typically considered for concrete type structures. Similarly, a long-term factor Ψ_l of 0.4 is used. The long-term deflection of a beam is typical two to three times the short-term deflection.

$$Stability_{long} = G + \varphi_l Q$$

It is important to control the deflection of a beam during the design and testing stages. The loading code outlines the appropriate guidelines for deflection limits. In this design, we followed the maximum final deflection should not exceed the lesser of span/300 or 10 mm. It is important to remain within these deflection limits to ensure the beam does not visually deflect and does not damage the materials.

5.4.4.2 Ultimate Limit State

The ultimate limit state considers the strength and stability of a beam. In this building systems case, the governing state will be strength. The strength limit state represents the potential modes of structural failure. It refers to the loss of equilibrium and stability of a beam. Strength limit state designs considers the strength capability of a beam, which typically considers the yielding and buckling of materials. In other words.

$$Required\ Strength \leq Nominal\ Strength$$

The required strength of a beam is represented by the maximum moment computed for the beam under load. The nominal strength represents the predicted capacity of the beam. In a typical beam analysis, design specifications like axial force, bending moment, shear force, and reaction force are all considered. A number of appropriate combinations have been considered and are set out in AS1170.0 and can be seen in table 10.

Formula	Description
$1.35G$	Permanent action only
$1.2G + 1.5Q$	Permanent and imposed action
$1.2G + 1.5\psi_1 Q$	Permanent and long-term imposed action
$1.2G + W_u + \psi_c Q$	Permanent, wind and imposed action
$0.9G + W_u$	Permanent and wind action reversal
$G + E_u + \psi_E Q$	Permanent, earthquake and imposed action
$1.2G + S_u + \psi_c Q$	Permanent action, actions given in Clause 4.2.3 AS1170.0 and imposed action

Table 18 - Strength Ultimate Limit State Combinations

6. Safety and Risk Assessment

6.1 Safety Procedures and Costing

Safety is an important aspect when it comes to building systems. The purpose of this innovative flooring system was to reduce cost and on-site labour, while maintaining the safety of its users. This flooring system has achieved a lightweight structure which allows for ease during manufacture and installation. Safety procedures have been continuously assessed throughout the development of this flooring system to ensure product success.

6.2 Assessment of Risks

All engineering activities involve both personal risk and project risk. Risk management plans are developed to minimise and control these risks. It is important to understand and follow the following four steps to help manage potential risks.

- Identify Hazards: find things that could potentially cause harm to people. Could arise from the equipment, materials, or the physical work environment. During the testing stages of this project, large machinery and equipment was used. All testing was completed at the USQ laboratory, which have the appropriate signage and identifications of potential hazards in the area.

- Assess Risks: considering what could happen and the likelihood of it happening. A risk management plan helps to determine the severity of the risk, existing control measures, and the urgency of the risk. Prior to testing day, a risk management plan was outlined and completed to assess the potential risks.
- Control Risks: managing the risks involves eliminating the risks to a practical manner. It is important when working with large machinery and equipment to have a controlled environment. The testing was completed in a USQ laboratory with all the appropriate control measures. The appropriate PPE was used throughout the testing stages which assisted in controlling the potential risks.
- Review Control Measures: control measures that are put in place should be reviewed regularly. The USQ laboratory reviews their control measures under the WHS Regulations regularly. Quality assurance processes need to be developed for new systems. This ensures that the product can effectively minimise health and safety risks.

6.3 Risk Management Plans

A risk management plan is a document that considers and prepares for risk. USQ has prepared a Safety Risk Management System for all research students to identify, assess and control the risk to the professional project. This process involved four important steps:

- Hazard Description: A hazard is a situation with the potential for harm in terms of human injury, damage to property, or damage to the environment. This step assesses what could cause harm.
- Likelihood: Represents the likelihood of the consequence occurring in the event of the hazardous situation previously described. This step assists in understanding the nature of the hazardous situation.
- Impact: The degree of harm that the hazardous situation might result in. This step assesses the potential impact on objectives, productivity, or harm of the situation.
- Mitigation Strategies: Designed to eliminate, reduce of control the impact of the known hazard. This step assesses the most effective control measure for the hazardous situation. Knowledge, availability, and cost all weigh into the result.

6.3.1 Personal Risk

Personal risks are known to be a lower-level risk. These risks or hazards may positively or negatively affect one of more of the project objectives. This personal risk assessment will aim to determine the best way to eliminate or control the hazard.

Personal Risks			
Hazard Description	Likelihood Low/Medium/High	Impact	Mitigation Strategies
Working at a Height	Medium	Medium	The use of temporary scaffolding. Appropriate awareness training.
Safety Hazards	High	High	Communicate safety policies with ongoing awareness assessments.
Manual Handling	Medium	Medium	Assess the capabilities of the individual.
Collapse	Low	High	Follow appropriate standards and guidelines on the product.

Table 19 - Personal Risk Assessment

6.3.2 Project Risk

Project risks have been generally known to be a higher-level risk. This is usually an uncertain situation that can have a drastic effect on the project's objectives. This personal risk assessment will aim to determine the best way to eliminate or control the hazard.

Project Risks			
Hazard Description	Likelihood Low/Medium/High	Impact	Mitigation Strategies
Labour Shortages	Low	Low	Prepare for potential changes in the industry. Arrange for alternatives.
Productivity Issues	Low	Low	Appropriate initial training and ongoing training to increase productivity.
Health Hazards	Medium	High	Communicate health policies with ongoing awareness assessments.
Safety Hazards	Medium	High	Communicate safety policies with ongoing awareness assessments.

Table 20 - Project Risk Assessment

The risks involved in designing, documenting, and distributing a new innovative building system needs to have the appropriate risk guidelines established. This dissertation outlines some common personal and project risks that may occur during the construction and lifespan of the system. A more extensive risk assessment plan should be developed to further validate the innovative building system into the industry.

7. Resource Planning and Requirements

7.1 Resource Development

Various resources need to be purchased and assembled to ensure this project achieved its objective. Materials required include polystyrene, wood, metal sheet envelope, timber stringers, and glue.

The testing of these sandwich panels was completed in the laboratory at USQ Toowoomba. The testing of the 3 planks and 2 beams was completed in one day. But due to the scope of this research project, only 1 plank and 1 beam was researched, certified, and validated. Setting up, testing, reconfiguring, and packing up or material needed to be done safely and accurately. The booking of the USQ laboratory (F11) was organised prior to the day of testing.

Throughout the research, testing and documentation stages of this project, continuous access to Australian Standards (AS1170, AS3600, AS4100, AS4600, etc) and the National Construction Code (NCC). These professional documents provide minimum requirements for safety, health, and sustainability for innovative buildings systems which need to be followed.

In terms of time resources, this dissertation will require over 400 hours of student time. This considers planning, research, testing, recording of data, and communication with supervisors. The contribution of both my time and the supervisors involved will be a key component to this project success rate.

7.2 Quality Assurance

To ensure quality assurance throughout this project, various measures and checks were implemented. This helped limit and potentially eliminate inaccuracies.

- 5.4. Desktop Analysis: This stage of the project aimed to develop the basic structural capability of the proposed system. It was important that this analysis was developed with quality and checked regularly by all parties. Developing an extensive analysis provided a basis and allow for a comparison of theoretical and physical testing.
- 9. Testing: Throughout the testing stage, regular checks and comparisons were completed. The theoretical analysis was used to help validate the testing data.
- 3. Literature Review: The literature review stage provided important information on the current systems being used in today's construction industry. Regularly confirming the data is up to date and accurate, quality assurance was achieved.
- Documentation: During the write up stages, regular checks were done after each critical project phase. These typically occurred during the submission dates and occurred more frequently as the dissertation extends. All feedback was applied.

8. Timeline

	Semester 1 (ENG4111)																				Semester 2 (ENG4112)													
							Recess									Exams			Recess												Recess			
Week	1	**2**	3	**4**	5	6	7	8	9	10	11	12	13	**14**	15	16	17	18	19	20	21	22	23	24	25	26	27	28	**29**	30	31	32	33	**34**
Week Ending (W/E)	26.2.	5.3.	12.3.	19.3.	26.3.	2.4.	9.4.	16.4.	23.4.	30.4.	7.5.	14.5.	21.5.	28.5.	4.6.	11.6.	18.6.	25.6.	2.7.	9.7.	16.7.	23.7.	30.7.	6.8.	13.8.	20.8.	27.8.	3.9.	10.9.	17.9.	24.9.	1.10.	8.10.	15.10.
Activity																																		
1. Initial Documentation																																		
1a. Statement of Aims and Objectives																																		
1b. Background Information																																		
1c. Project Specification																																		
2. Literature Review																																		
2a. Assessment of Traditional Flooring System and Cost																																		
2b. Current Australian Building Alternatives																																		
2c. Research into EPS with Fire Retardant																																		
3. Project Outcomes																																		
3a. Desktop Analysis																																		
3b. Final Design Development																																		
3c. NCC Pathway Research																																		
4. Development Process																																		
4a. Concept Development																																		
4b. Feasibility Study																																		
4c. Patenting																																		
4d. Design and Development Planning																																		
4e. Manufacture																																		
4f. Testing and Validation																																		
5. Methodology																																		
5. Development Methodology																																		
6. Risk Assessment																																		
6a. Safety Procedures and Costing of Innovative Product																																		
6b. Assessment of Risks																																		
6c. Investigate Risk Management Plans																																		
7. Resource Planning																																		
7a. Schedule Access and Gather Supplies																																		
8. Testing																																		
8a. Physically Test Design																																		
8b. Compare with Design Criteria																																		
8c. Testing Write Up																																		
9. Documentation																																		
9a. Prepare Dissertation Draft																																		
9b. Submit Progress Report																																		
9c. Submit Partial Dissertation																																		
9d. Make Final Alterations																																		
9e. ENG4903 Conference																																		
9f. Dissertation Submission																																		

Key:	
	Expected Week to Complete Task
	Tasks Successfully Completed
	Overdue Tasks
	Important Submission Milestones

9. Results and Discussion

9.1 Final Design

9.1.1 Plank

The final plank design was manufactured as 4.8 m long x 600 mm wide x 100 mm thick. The plank consisted of a L grade EPS centre divided by grade F11 12 mm structural plywood timber stiffeners at approximately 530 mm centres. The four corners were comprised of 70 mm wide timber stringers that were used to bond the sheet metal around the top chord.

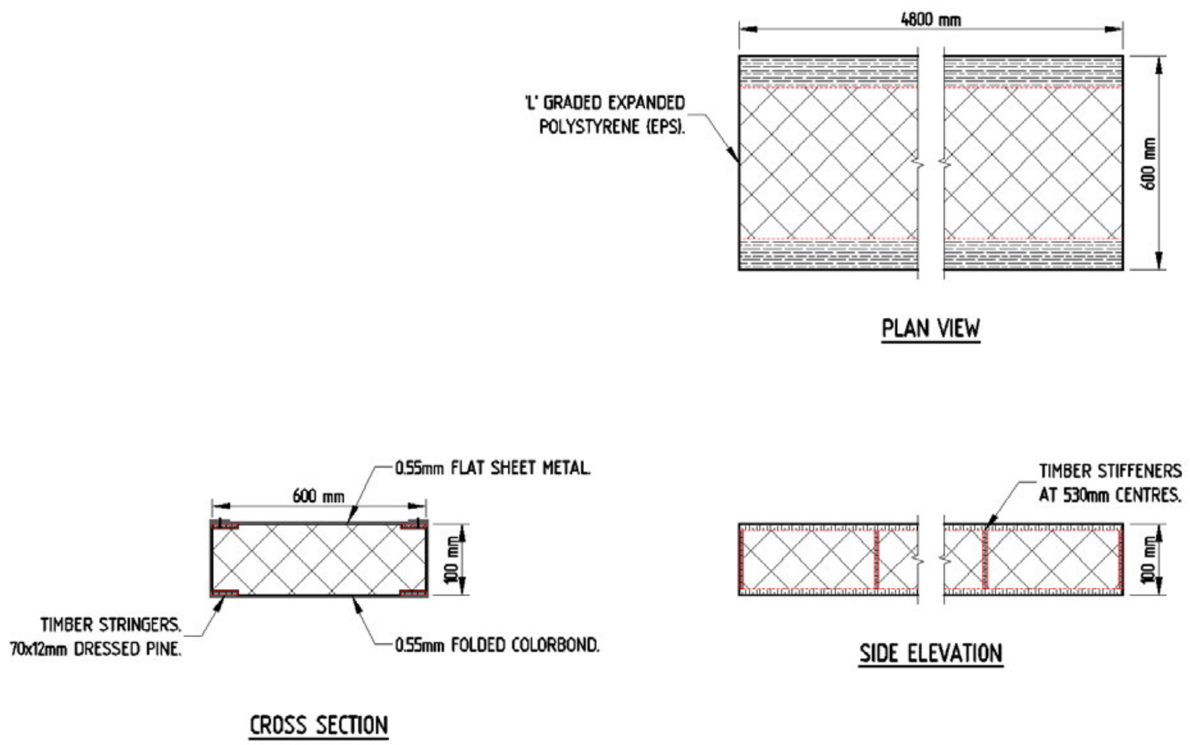


Figure 17 - Building Solution Plank Final Design

9.1.2 Beam

The final beam design was manufactured as 4.8 m long x 100 mm wide x 300 mm deep. The beam consisted of a L grade EPS centre divided by grade F11 12 mm structural plywood timber stiffeners at approximately 335 mm centres. The structural plywood was also used for the top and bottom chords.

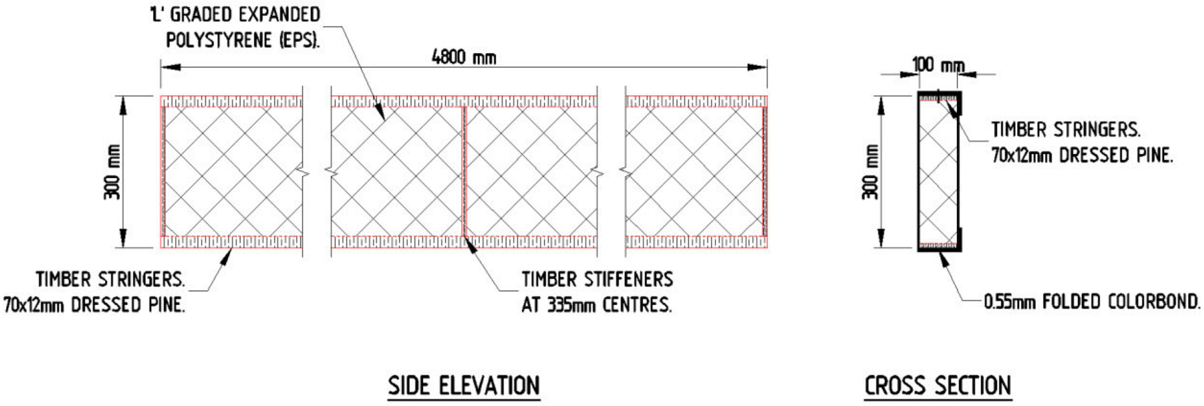


Figure 18 - Building Solutions Final Beam Design

9.1.3 Predictions

The desktop analysis provided theoretical information that assisted in performance predictions. Physical testing endured applying a uniformly distributed load (UDL) on the flooring system and an equally spaced point load (PL) on the beam. These empirical techniques chosen assessed the bending performance of the manufactured plank and beam. Testing aimed to provide practical information regarding how the building system will fail under an applied load.

When a uniformly distributed load is applied to a plank, the magnitude of the load remains uniform throughout the span of the plank. The planks mode of deflection is primarily by its bending performance.

When a point load is applied to a beam, it results in reaction forces at the beams support points. These forces acting on the beam will produce shear forces and bending moments, that in turn generate internal stresses, strains, and deflections of the beam.

It was predicted that under load, the EPS foam will be compressed in the centre. A possible building solution could be to use a high-density foam to reduce the likelihood of this failure. A downside to this alteration would be an increase in cost which may not be worth the associated benefits.

Once the foam is compressed, it is predicted that buckling of the top sheet will occur, as thin steel on the top face has minimal compressive strength. The configuration and length of the metal was considered prior to development and testing. An overlap on the top of the plank will provide more benefits as to if the metal was rotated to the bottom. The length of fold was another variable that was considered and needed to be proven during testing. An initial overlap of 100 mm to 150 mm was chosen.

9.1.4 Setup

The planks and beams were assembled in late June by the building system designer and structural engineer. After careful consideration, an average of 4 metre spanning length was chosen for testing. The day of testing was mutually agreed for Tuesday 6th July 2021 at the USQ laboratory in Toowoomba. All included parties were in attendance to observe the testing process.

9.1.4.1 Plank

The uniformly distributed load test was done on the plank (4.8 m long x 600 mm wide x 100 mm thick). This load test is designed to imitate a typical force applied over an area, in this scenario being the width of the plank. The uniformly distributed load was achieved by laying 4.0 x 4.0 m^2 air bags below the plank. This load test was set up to imitate typical loading once coverings have been installed.

Figure 19 - Simply Supported Plank Setup with UDL

Once the plank was set in place, a free body diagram was developed to show all dimensions and forces on the plank. The total load per unit length and span length will be used for the post testing analysis of the plank.

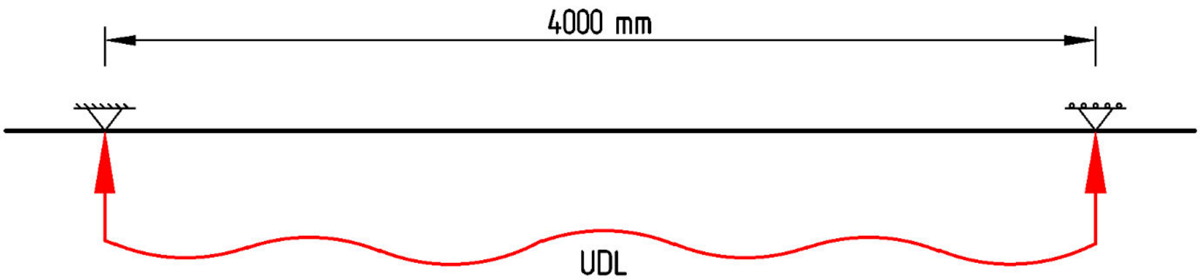


Figure 20 - Simply Supported Plank Free Body Diagram

9.1.4.2 Beam

The point load test was done on the beam (4.8 m long x 100 mm wide x 300 mm deep). This load test is designed to imitate a typical force being applied at a set distance from the ends of the beam. This load test was set up for two-point loads equally spaced from the centre of the beam. The testing load with split into two via a spreader beam. A gradual point load in kN was to be applied at the centre of the beam.

Figure 21 - Simply Supported Beam Setup with Equally Spaced Point Loads

Once the beam was set in place, a free body diagram was developed to show all dimensions and forces on the beam. The total concentrated load, span length, and the distance to each point load will be used for the post testing analysis of the beam.

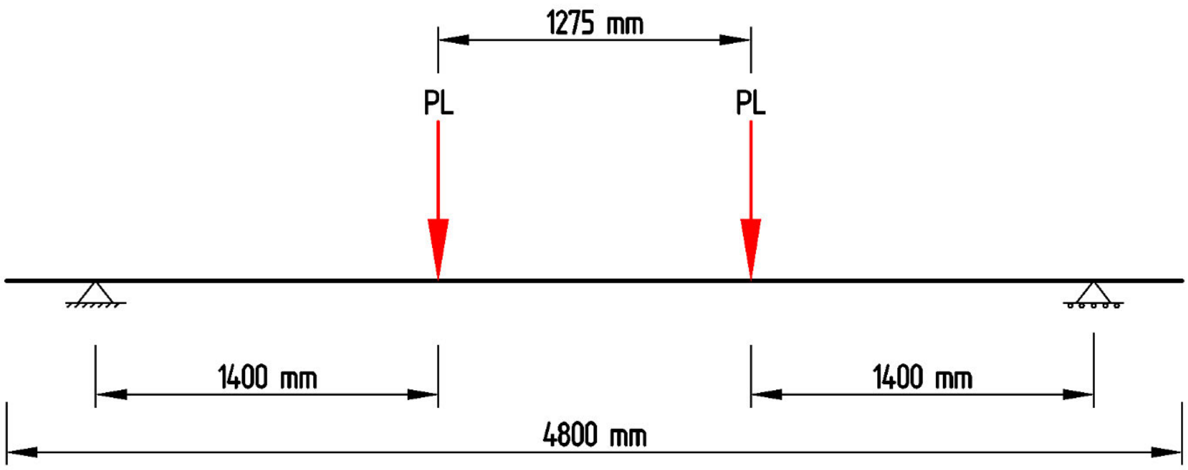


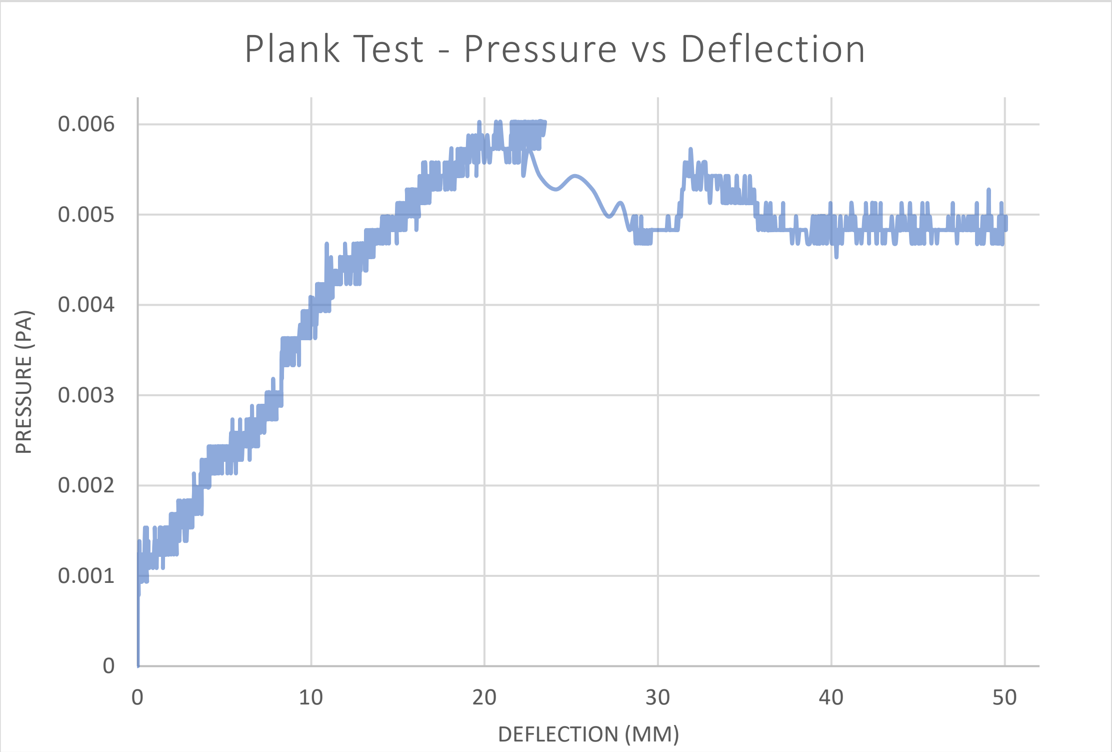
Figure 22 - Simply Supported Beam Free Body Diagram

9.1.5 Outcomes

During the testing process, detailed sketches, observations, photographs, and a full video for documentation was done. This allowed each party to reassess and revaluate the products performance under load and distinguish ways to improve the design.

9.1.5.1 Plank

The plank was found to be linearly proportional when the air bag pressures were performed. This means when the pressure was carried, there was a linear increase in the deflection. The plank was found to be elastic until its buckling state of approximately 60 kPa. The buckling state occurred when the plank reached a deflection of 22 mm. Once the plank buckled, the pressure dropped dramatically, but was able to continue to take pressure.



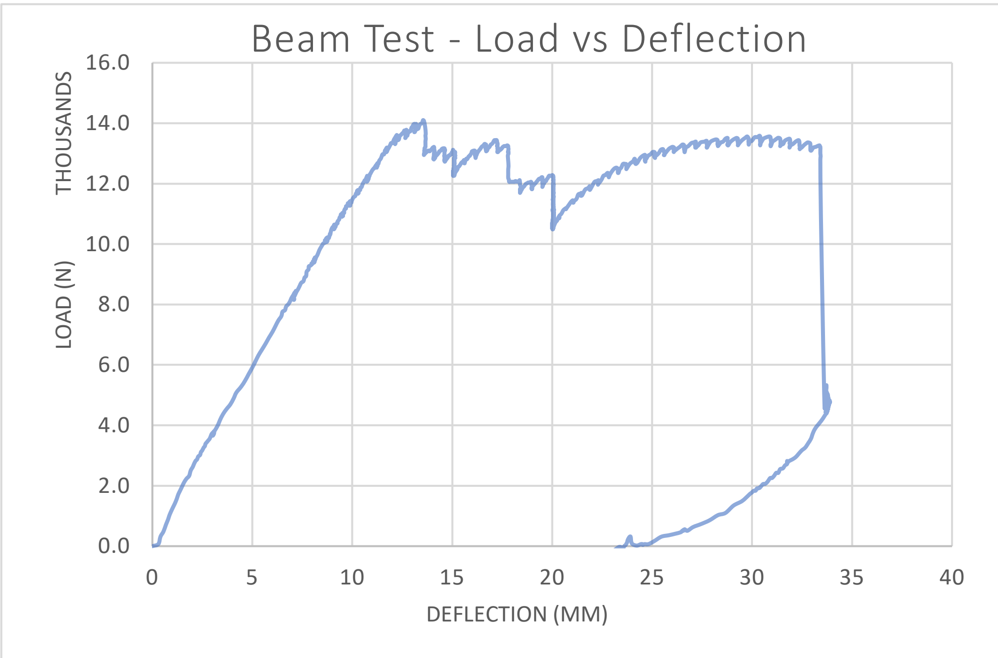
Graph 5 - Plank Test (Pressure vs Deflection)

9.1.5.2 Beam

The failure mode for the manufactured beam was found to occur on the top plate. The testing results and failure for the beam are consistent with the expectations laid out in the desktop analysis. Once the foam was compressed, buckling of the top sheet occurred. This is due to thin steel on the top face having minimal compressive strength. The setup for testing aimed to simulate the typical force applied for a simply supported beam. In the testing stages, it is difficult to distribute the load accurately and therefore may produce a more conservative result.

Figure 23 - Simply Supported Beam Failure Mode

The beam was found to be linearly proportional when the load was performed. This means when the load was carried, there was a linear increase in the deflection. The beam was found to be elastic until its buckling state of approximately 13 kN. The buckling state occurred when the beam reached a deflection of 12 mm.



Graph 6 - Beam Test (Load vs Deflection)

It was found that the limiting factor was deflection. The load at which this occurred was 34 kN or 3.5 tonne. The loading code outlines the appropriate loading combinations that a design must satisfy. For ultimate limit state designs, stability and strength are the governing factors.

9.1.6 Post Test Analysis

A comparison of the testing results and structural analysis provided information on how well the manufactured systems performs under an applied load.

9.1.6.1 Plank

The pressure in P and lasered deflections in mm was measured in deciseconds during the air bag test. For analysis purposes, the applied pressure in 1kPa increments was analysed. The measured deflection at each applied pressure was evaluated. From these measured values, the maximum moment can be calculated, and the point load can be interpolated.

Using the same increments, the deflection can be calculated manually using the bending theory. It is evident there is a difference in deflection values using the two methods. The comparison between the test deflection and calculated deflection shows the real-life disparity when it comes to designing and testing a new system. The calculated deflection is stronger as it assumes 100% connection between the beam elements. This is not possible under actual load. The percentage difference remains linear, until beam failure at 6 kN/m². A factor of safety should be established to allow for this inconsistency.

Results Comparison					
Pressure	Max Moment	Load (P)	Test Deflection	Calc Deflection	Δ Deflection
kN/m	kNm	kN	mm	mm	%
1	2.1	2.04	1.65	1.98	16.7
2	4.2	4.08	3.63	3.97	8.4
3	6.2	6.11	7.78	5.95	30.7
4	8.3	8.15	10.35	7.93	30.5
5	10.4	10.19	14.97	9.92	50.9
6	12.5	12.23	19.69	11.90	65.5

Table 21 - Plank Post Testing Comparison

9.1.6.2 Beam

The applied force in kN and lasered deflection in mm was measured in deciseconds during the point load test. For analysis purposes, the applied forces in increments of 2 kN were analysed. The measured deflection at each applied load was evaluated, the maximum moment was calculated, and the uniformly distributed load was interpolated.

Using the same increments of applied forces, the deflection was calculated manually using the bending theory. It is evident there is a difference in deflection values using the two methods. The comparison between the test deflection and calculated deflection shows the real-life disparity when it comes to designing and testing a new system. The calculated deflection is stronger as it assumes 100% connection between the beam elements. This is not possible under actual load. The percentage difference remains linear, until beam failure at 13 kN. A factor of safety should be established to allow for this inconsistency.

Results Comparison					
Force	Max Moment	UDL (w)	Test Deflection	Calc Deflection	Δ Deflection
kN	kNm	kN/m	mm	mm	%
2	1.4	0.67	1.58	1.35	17.1
4	2.8	1.35	3.29	2.71	21.7
6	4.2	2.02	5.14	4.06	26.5
8	5.6	2.70	6.80	5.41	25.6
10	7.0	3.37	8.55	6.76	26.4
12	8.4	4.05	10.55	8.12	29.9
14	9.8	4.72	13.49	9.47	42.5

Table 22 - Beam Post Testing Comparison

Span tables can be developed from the testing results of both the plank and beam. This will be beneficial for a designer or builder to understand while using this building system. The appropriate structural loadings are in accordance with AS1170.0 and AS1170.1. The spans are based on limit state design. The limit states are the conditions in which a structure is considered to fail the purpose for which it was designed and built. The initial design for this innovative building system will consider residential and domestic buildings, otherwise known as class 1 buildings from AS1720.3.

9.1.7 Span Tables

The physical testing validated the structural capability of both systems. It was proven that these innovative building systems provide a possibility for builders to save both time and money during construction. The results provide an opportunity to develop structural span tables for both building systems. Span tables show the load capacities and limitations for each building system. Using an appropriate loading case from AS1170.1, these tables will provide the clear distance between supports that the systems can maintain until the deflection limitation is met.

Plank Span Guide		
Plank Width	600	mm
Plank Thickness	100	mm
Selected Pressure	5	kPa
Core Density	13.5	kg/m³
Deflection Limit	12	mm
Length mm	**Deflection** mm	
2000	0.58	
2500	1.41	
3000	2.91	
3500	5.40	
4000	9.21	
4500	14.75	
5000	22.48	
5500	32.91	
6000	46.62	

Beam Span Guide		
Beam Width	100	mm
Beam Thickness	300	mm
Selected Force	10	kN
Core Density	13.5	kg/m³
Deflection Limit	10	mm
Length mm	**Deflection** mm	
2000	0.67	
2500	1.76	
3000	3.09	
3500	4.66	
4000	6.47	
4500	8.53	
5000	10.82	
5500	13.36	
6000	16.14	

Table 23 - Span Tables

The above span tables provide information on span capabilities for each building system. By developing these tables, it assisted in the decision-making process for future development. These tables can be used to determine spanning capabilities and provide conclusions on the applicability of market opportunities for both systems. It is evident that both systems have the structural capability to compete with the traditional bearer and joist construction. For both building systems, adopting a 4-metre loading span would be the most feasible solution. This can clearly compete with the existing standard timber joist spacing of 4.5 metres.

Further investigation into material variables could increase the spanning capacities of each building system. Ongoing material refinement could broaden the use of these innovative building systems. For example, options for a raft slab design, mezzanine, or suspended slab flooring.

9.1.8 Performance Comparison

It is important to compare the new building systems with existing similar products in the market. The test data is a base line for building comparisons. The manufactured beam is a representation of a foam filled steel wrapped beam. The manufactured beam has the potential to become a viable alternative for Laminated Veneer Lumber (LVL) or SmartLam Glue Laminated Timber (GL17S). Both hardwood alternatives are made from multiple layers of veneers bonded together with structural adhesive that provide for longer spans, heavier loads, and complex shapes. These improved characteristics do come with a heavy price tag.

For preliminary purposes, the computer program from Tiling Timber, 'Smart Frame Design', will be used to design the appropriate timber beam for comparison. A standard residential double garage lintel situated in Toowoomba will be designed.

- $Double\ Garage\ Span = 4.8\ m$
- $Roof\ Truss\ Span = 8\ m$
- $Typical\ Overhang = 0.6\ m$
- $Standard\ Roof\ Pitch = 20\ °$
- $Standard\ Truss\ Spacing = 0.9\ m$

Using these geometry parameters to calculate the roof load width of the residence.

$$RLW = \frac{4000}{\cos(20°)} + \frac{600}{\cos(20°)} = 4895.22\ m$$

An average roof load width of 5 metres will be used for this preliminary calculation.

The following load parameters have been assumed from AS1170.1:

- $Steel\ Sheet\ Roofing \rightarrow 0.75\ mm\ thick$
- $Plastic\ Ceiling \rightarrow 13\ mm\ thick$
- $Roof\ and\ Ceiling\ Battens \rightarrow standard$
- $Lightweight\ Insultation \rightarrow standard$
- $Stud\ Wall \rightarrow 10\ mm\ Plasterboard$
- $Roof\ Dead\ Load = 30\ kg/m^2$
- $Wall\ Dead\ Load = 42\ kg/m^2$
- $Garage\ Door\ Weight = 1\ kN$

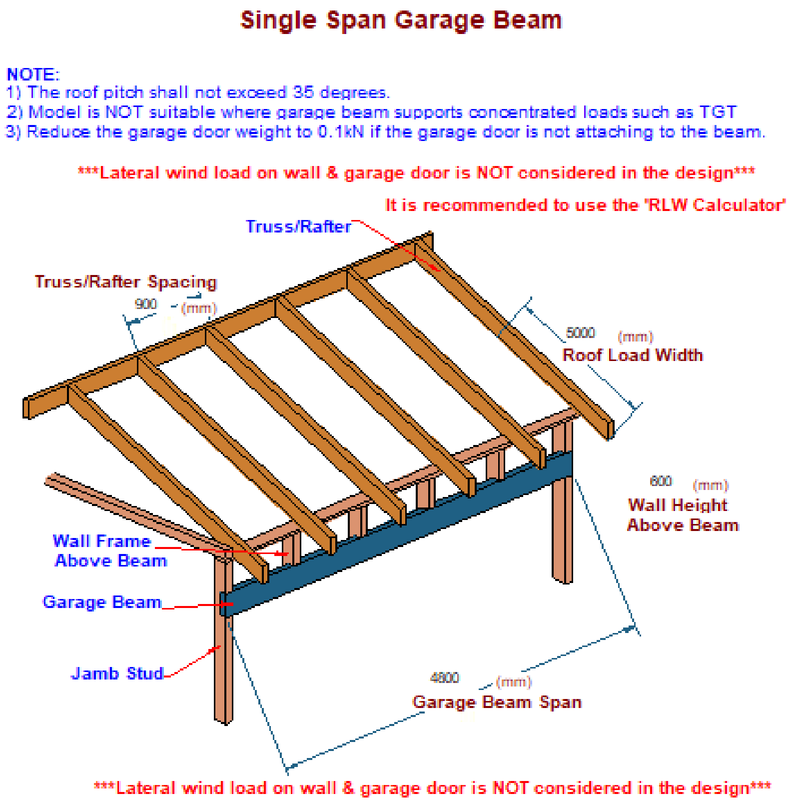


Figure 24 - Smart Frame Inputs

The geometry and loading parameters produce a range of results. The capacity of the member (maximum 85%), deflection (maximum 10 mm) and cost of each timber alternative will be collected for comparison.

- 300x75 Smart LVL15.
  - Capacity: 83%
  - Deflection: 8 mm.
  - Cost: $53 /m (reviewed 9th August 2021).
- 2/360x75 Smart LVL15.
  - Capacity: 85%
  - Deflection: 9 mm.
  - Cost: $125 /m (reviewed 9th August 2021).
- 295x85 GL17S.
  - Capacity: 68%
  - Deflection: 7 mm.
  - Cost: $160 /m (reviewed 9th August 2021).

The above timber comparisons were selected from similar dimensions to the manufactured beam. The compared deflections demonstrate the innovative building beam is a viable comparison. There is a substantial difference between the costing of the timber comparisons and costing of the innovative building beam. This section aimed to compare the performance of the innovative building beam and current engineered timbers. This performance comparison has been deemed effective.

10. Conclusions and Recommendations

This study has followed the creation of a new innovative building system consisting of a floor plank and beam. The purpose of this flooring system was embarked through flexural testing and design. The importance of this topic was apparent through industry perception, proving that Australia's building industry is

The purpose of this study was to research and develop a non-fire rated prefabricated flooring system for the building industry. These innovative building systems consisted of an expanded polystyrene (EPS) core, timber stringers for bondage, covered in thin sheet metal for protection. The floor plank and beam proved to have the structural capability when compared with other engineered timber. Through further research and development, this innovative building system could provide the building system developer and the industry with a viable alternative to traditional flooring.

The literature review revealed that the residential building industry has been generally resistance to change and acceptance of new flooring systems. Reduced labour and material shortages can be the catalyst for new building systems to be accepted, as this may force builders to think differently. Due to the timber shortages occurring throughout Australia, now is the prime time to design and adopt a building alternative.

A step-by-step development process for an Australia innovative building system was created to assess the product's potential for success. This study followed the development process rather than performing it. This step-by-step development process, it assisted in answering the important questions. What is the purpose for this building system? Why is it needed in the industry? What new aspects does it bring to the industry? Who does it benefit?

Physical testing was completed on the floor plank and beam to determine how well the systems will perform under load.

10.1 Plank

- Manufactured as a 4.8 m long, 0.6 m wide, 0.1 m thick plank.
- Tested using a uniformly distributed load (UDL).
- Plank reached a buckling state of 6 kN/m^2.
- Corresponding deflection of 20 mm.

10.2 Beam

- Manufactured as a 4.8 m long, 0.1 m wide, 0.3 m deep beam.
- Testing using two-point loads equally spaced from the centre.
- Beam reached a buckling state of 13 kN (1.3 tonne).
- Corresponding deflection of 12 mm. This is within the limits set out in AS1170.1.
- Compares with engineered timbers LVL and GluLam.

Theoretical analysis and physical testing proved both innovative building systems have the structural capability to compete with the traditional bearer and joist construction. Using the outcomes of the testing, further investigation into material variables could benefit to final system. Ongoing material refinement and building configurations could broaden the use of these innovative building systems, like possibilities for suspended flooring or slab on ground capabilities.

This dissertation critically reviewed the traditional bearer and joist flooring system, assessed the current building alternatives in Australia as well as researched into EPS safety issues. The literature review provided new insight and opportunities to further the research plan. The physical testing results were interpreted and provided opportunities to advance in the field. This dissertation reveals originality in the systems work.

11. Further Work

The testing results and span tables proved the innovative building system have the structural capability to be a viable flooring alternative. The investigation undertaken in this report cannot capture all aspects associated with this topic. As a result, there are a range of items which would ideally require further review and investigation to ensure full potential of the topic.

- The literature review found safety issues around using EPS in residential and light industrial buildings. Although current research provided opportunities to develop using such product, it may only be a matter of time before this building material is banned for single residential applications in Australia.
- Investigation into material variables could benefit the final system. Ongoing material refinement and building configurations could broaden the use of these innovative building systems, like possibilities for suspended flooring or slab on ground capabilities.
- Additional testing to gather more profound data on aspects like the ultimate failure modes and behaviour of the combined materials should be explored.

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13. Appendix A

ENG4111/4112 Research Project

Project Specification

For: Amber Reid

Title: Development of an Innovative Flooring System for Residential and Light Industrial Buildings.

Major: Civil Engineering

Supervisors: Gary Elks

Enrolment: ENG4111 (Research Project Part 1) – ONC S1, 2021

ENG4112 (Research Project Part 2) – ONC S2, 2021

Project Aim: To design and test an innovative flooring system that can be incorporated into residential and light industrial buildings. Developing a step-by-step development process for this floor system will assist in examining the future success of the innovative product.

Programme: Version 2, 27th May 2021

1. Review the existing bearer and joist non-fire rated flooring system and its limitations in the building industry.
2. Review the safety procedures for handling and installing the traditional bearer and joist flooring system.
3. Review the costing involved in the traditional bearer and joist flooring system.
4. Develop a step-by-step development process for Australian innovative building systems.
5. Develop Australian patent claim guidelines for the building system.
6. Design the floor plank and beam system using different combinations of materials and joining techniques.
7. Physically test various configurations to validate the design criteria.
8. Undertake a cost analysis of the proposed floor plank in comparison to the traditional bearer and joist flooring system.

If time and resources permit:

9. Do a test installation to identify ease of installation, handling, and installation issues. Compare with the existing bearer and joist flooring system.
10. Install various floor coverings and assess the capability of the system to carry flooring layers safely without affecting the design.

Appendix B

Classifications of buildings and types of construction set out in the NCC.

Classes of Building		
Class 1	Class 1a	A single dwelling being a detached house, or one of a group of two or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit.
	Class 1b	A boarding house, guest house, hostel or the like with a total area of all floors not exceeding 300m², and where not more than 12 people reside, and is not located above or below another dwelling or another Class of building other than a private garage.
Class 2	A building containing 2 or more sole-occupancy units each being a separate dwelling.	
Class 3	A residential building, other than a Class 1 or 2 building, which is a common place of long term or transient living for a number of unrelated persons. Example: boarding-house, hostel, backpackers accommodation or residential part of a hotel, motel, school or detention centre.	
Class 4	A dwelling in a building that is Class 5, 6, 7, 8 or 9 if it is the only dwelling in the building.	
Class 5	An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.	
Class 6	A shop or other building for the sale of goods by retail or the supply of services direct to the public. Example: café, restaurant, kiosk, hairdressers, showroom or service station.	
Class 7	Class 7a	A building which is a car park.
	Class 7b	A building which is for storage or display of goods or produce for sale by wholesale.
Class 8	A laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale or gain.	
Class 9	A building of a public nature.	
	Class 9a	A health care building, including those parts of the building set aside as a laboratory.
	Class 9b	An assembly building, including a trade workshop, laboratory or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class.
	Class 9c	An aged care building.
Class 10	A non-habitable building or structure.	
	Class 10a	A private garage, carport, shed or the like.
	Class 10b	A structure being a fence, mast, antenna, retaining or free standing wall, swimming pool or the like.
	Class 10c	A private bushfire shelter.

Types of Construction		
Rise in storeys	Class of building 2, 3, 9	Class of building 5, 6, 7, 8
4 or more	A	A
3	A	B
2	B	C
1	C	C