NATIONAL INSTITUTE FOR FOREST PRODUCTS INNOVATION

Final Report
Project NT015

Developing a New Generation of Tasmanian Appearance Hardwood Products for In-State Design and Manufacturing

2023

Launceston Centre

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Developing a New Generation of Tasmanian Appearance Hardwood Products for In-State Design and Manufacturing

Prepared for

National Institute for Forest Products Innovation

Launceston

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Executive Summary

This project demonstrates a design-led project in the Tasmanian timber industry to generate novel engineered appearance wood products for in-state manufacturing. Previous reports have documented the design journey, knowledge creation and concept development over the course of the project.

Most project deliverables (PD 1-5) have been met and evidenced in previous Milestone Report 2 and 3 and in this Final Report (see Table 1). There is one part of PD6 that remains incomplete as we wait for the results of in-service performance trial due to finish in February 2023 to then present to industry and the market for their feedback.

Table 1: Summary of how project deliverables have been met and where materials are reported

PD1	• Analyse opportunities for new product designs and manufacturing	Report 2
PD2	• Detail the possible use of native and plantation hardwood timbers in design and manufacturing	Report 3 & Final Report
PD3 and 5	• Detail new appearance sawn timber and veneer-based products developed including engineered wood products	Report 3 & Final Report
PD4	• Produce tangible prototypes and products developed with commercial processes and advanced manufacturing	Report 3 & Final Report
PD6	• Show initial market perceptions of a new engineered flooring product and how hardness impacts their timber flooring selection.	Final Report

The focus of this report is to present the concluding stage of the project; production ramp-up and industry trials. Key to this stage of the project was to demonstrate and validate the manufacturing process for an engineered timber flooring product in conjunction with project partners using in-state commercial practices. Further to this the comparative testing of low-density plantation timber flooring prototypes with an existing market competitor.

In the following report *E. nitens* is often described and differentiated by the silviculture management for a tree grown for fibre (pulpwood) or sawlog. The key difference being in an appearance product is the concern and occurrence of knots or clear wood. It is further acknowledged that different performance characteristics exist between the butt and second log, but this information was not collected or available for this project and requires further investigation.

Other commercial trials included the performance of existing solid timber products as an overlay for a heated slab in new buildings at the University of Tasmania and testing the suitable use of *E. nitens* for mouldings such as dowels and other profiles.

The project, to develop a new generation of Tasmanian appearance hardwood products for in-state manufacturing began in 2019 and completed at the end of 2022. The small amount of market testing remaining will be completed as part of grant funded PhD work and reported to industry partners.

There have been a number of successful outcomes from this project:

- **Acoustic wall panels** using advanced manufacturing tools to showcase fibre managed *E. nitens* through pattern generation around knots. Proof of concept being trialled in Forico open plan office space.
- **In-service flooring trials** comparing fibre and sawlog managed *E. nitens* with existing competitors. The trials have demonstrated the positive performance of sawlog managed *E. nitens* despite it having on average a lower hardness rating than *E. obliqua* and other existing hardwood species in the flooring market.
- **In-state manufactured engineered flooring prototypes** using different thicknesses of *E. nitens* veneers and lamellas on *E. nitens* plywood substrate, as well as testing differences between sawlog and fibre managed, and densified *E. nitens*.
- **Innovation award** (2022) for new strip timber flooring on heated subfloor using *E. globulus* from the University of Tasmania. Four different hardwood species overlays were installed and tested on

a heated slab, and all appear to be fit-for-purpose during a winter heating cycle. This work has led to its commercial use in new university buildings at Inveresk campus.
- Overall, **increased familiarity and confidence** in the suitable uses, properties, and processing of plantation *E. nitens* (sawlog and fibre managed) by industry and research partners.

Despite a smaller number of products being developed with commercial processes and advanced manufacturing than envisioned, the benefits resulting from this project and concurrent NIFPI projects in CSAW were several:

- The **expansion of research capabilities and skills** to support local forestry and wood product sector through training the next generation through higher degrees such as PhDs (n=3) and mentoring tenured UTAS staff (n=3)
- Providing a **low-level risk of exposure** between foresters, scientists, timber processors, researchers, and designers to **establish trust, exchange, and collaboration** opportunities into the future. There is now a better level of understanding of what is involved from the tree to the log, to the timber board and products.

Over the course of the project a number of changes and complications took place that ultimately influenced the design process, product development, the number of tangible prototypes developed and time taken. These are briefly outlined as they are important to acknowledge the unintended impacts and lessons for future projects:

- **Competitive labour markets and expertise shortages** in the timber industry and research resulted in many changes to personnel, capabilities and skills which led to some lines of investigation to be modified or suspended (interior linings).
- **Worldwide pandemic led to lockdowns**, disruptions in transport, markets and labour, and the demand for timber spiked with a construction led recovery. As a result, further delays occurred across the supply chain, industry partners and researchers, especially when specific logs needed to be harvested, transported, broken down, tested, seasoned, milled, tested, and developed into engineered products using novel plantation resources.
- **Construction delays on our building and campus** meant restricted access and operations of the workshop/laboratory equipment for CSAW researchers from December 2020 and until relocated to new facility in September 2021 where equipment needed to be commissioned and recalibrated.

The project, both benefited and was challenged by the length of time and the number of industry partners involved. The length of time allowed for many parties to be involved and allowed for an in-depth documentation and understanding of all processes involved from log to timber product. With so many partners it was difficult to maintain engagement in one overarching project, but it meant that there were enough partners to sustain this, as well as engage in some smaller product tests with the different needs of industry.

There are many future opportunities for lines of investigation and design work to assist in-state product development. In part, some of these areas are in response to the infancy of engineered products and processes involved and the on-going need to build skills and capabilities in industry and research. Areas identified:

- Evaluating the **performance of different coating systems** have on engineered timber flooring, in particular lower density plantation resources.
- Testing **alternatives to the use of formaldehyde-based glues** in plywood panels, interior lining products and engineered products due to concerns of indoor air quality.
- **On-going monitoring of live timber projects in-service (flooring/ battens).**
- Challenging performance requirements/ test methods and standards for appearance products, such as timber flooring.
- Extension of network and **partnership opportunities with joiners** on real commercial projects to further expand opportunities using CNC flat bed router.
- **Ways to bridge the conceptual difference between producing sawn and veneer-based commodity products with engineered products** and the use of advanced manufacturing tools.

Acronyms

EWF	Engineered Wood Flooring
IAF/ AFG	The Institute of Foresters of Australia/ Australian Forest Growers
NIFPI	National Institutes of Forest Products and Innovation
NTP	Northern Transformation Project at the Inveresk Campus, Launceston, University of Tasmania
LC college	Launceston College (Year 11 to 12), State funded school.
PD	Project deliverables
SC	Steering Committee
SFM	Sustainable Forest Management
STT	Sustainable Timber Tasmania
SWST	Society of Wood Science and Technology
TFFPN	Tasmanian Forest and Forest Products Network
UoM	University of Melbourne
UTAS	University of Tasmania

Contents

Introduction

Aims and objectives

The overall aim of the project was to develop a new generation of hardwood appearance products that can be manufactured in-state and that can extend existing and emerging timber resources into high-value architectural applications. This involved exploring and developing products, determining product feasibility and innovation adoption by industry, and identifying in-state product development opportunities.

In this report the production ramp-up journey of an engineered wood flooring product is documented to illustrate how a novel timber concept for in-state manufacturing with Tasmanian hardwoods was developed. The project was design-led and using design skills and processes to generate, test and evaluate new appearance products. A range of deliverables were generated including:

- Design exploration through prototyping
- Design concepts informed by new material knowledge and wood science
- Exploration with wood modification techniques such as densification
- 1:1 commercial scale installation of products for testing and evaluation.

Project milestones

This report presents four key components to the project deliverables:

- New commercial strip timber flooring research and development on a heated slab (PD4)
- Interviews with architects and manufacturers about flooring applications and markets (PD6)
- Production ramp-up of several flooring prototypes specifically developed for the project (PD4-5)
- Post production ramp-up testing and evaluation of prototypes for abrasion (PD3)

Product design and development

This project employed timber design expertise and skills alongside an industrial design methodology to consider new applications for Tasmanian timber resources through methodical prototyping and testing to explore a variety of design outcomes and new products that can be manufactured in-state. This project employed the six phases of the generic product design and development process, as described by Ulrich and Eppinger (2012) and shown in Figure 1.

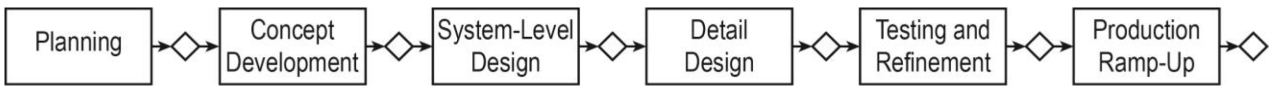


Figure 1 The generic product development process (Ulrich & Eppinger, 2012)

This report illustrates the process through an engineered flooring appearance wood product. While Figure 1 implies a linear progression through the product development process, the stages were iterative and informed by parallel testing and research. Key project milestones over the life of the project contributed to the overall process and informed the final engineered flooring appearance wood products.

Project journey

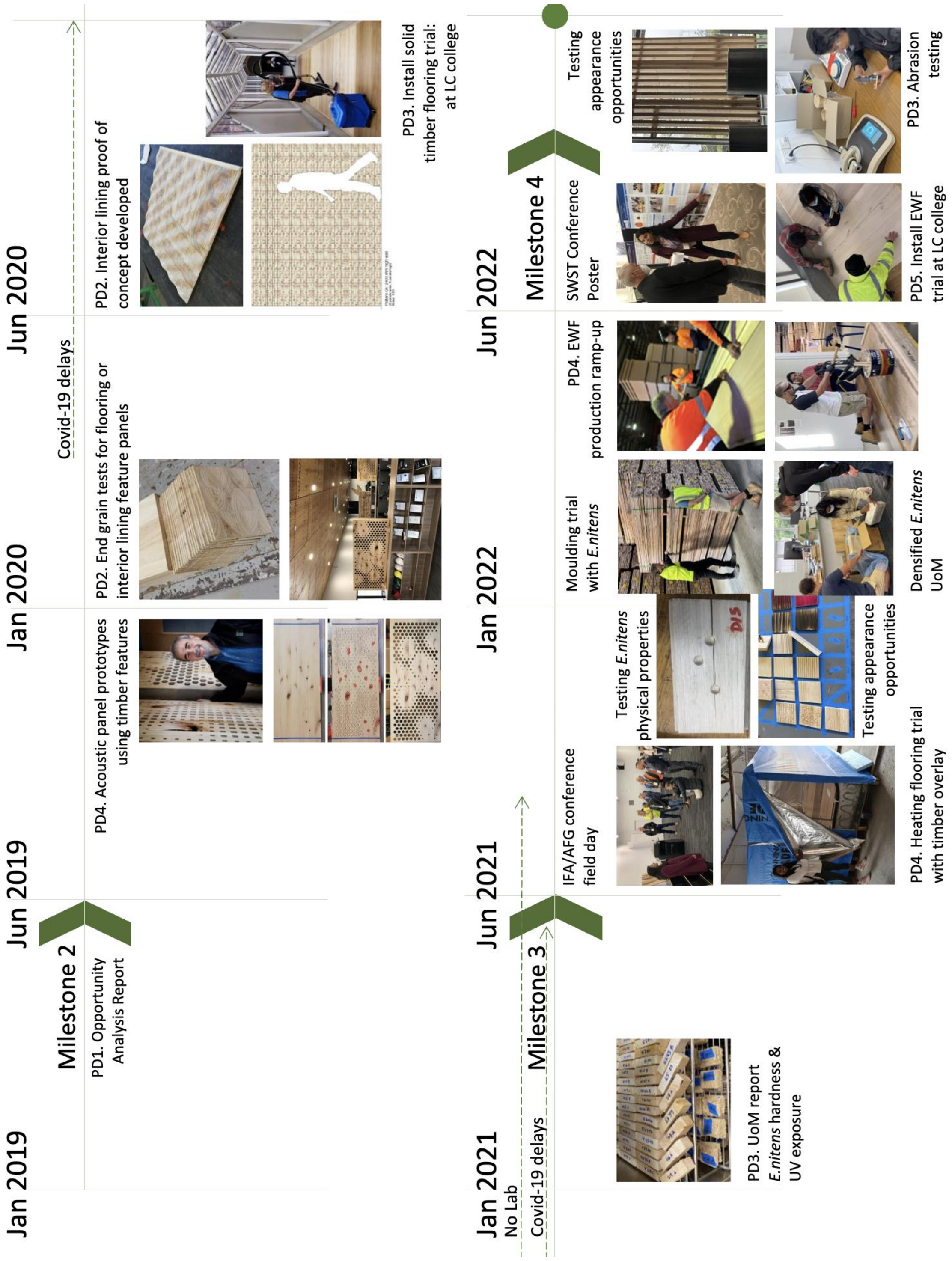
Over the course of the project there was several design investigations and activities as shown in Figures 2 and 3. Figure 2 provides a visual overview of key activities documented. Figure 3 maps these activities including key design developments along a timeline showing the Milestone stages. It also shows the periods of the grant that were disrupted by Covid-19 pandemic and the loss of our workshop lab facilities. The other key factor not shown here was the changes of key personnel, capabilities and skills that influenced some design investigations to be modified or suspended with consultation with industry partners.

The design process began with the research team developing an Opportunity Analysis Report to survey new products, processes, and use of technology in timber appearance products. This report formed part of Milestone 2. The report identified five overarching areas for investigation with a number of options:

1. Subtractive processes (subtractive & form)
2. Additive processes (dowelling, gluing, welding & friction)
3. Form processes (3d veneer forming)
4. Anatomic alterations (microwave & densification)
5. Surface finishes (colour, dye, staining & coating).

Industry collaborators identified their areas of interest for further concept development work and testing. Work began on subtractive processes using advanced manufacturing to generate parametric patterns based on the position of knots and high feature in laminated *E. nitens* boards. These became a series of panels to assist in acoustic attenuation trialled in an open office plan at Forico. Another line of investigation began with end grain flooring panels as part of additive processes. This design work and proofs of concept were done by Kotlarewski and Tanton.

Figure 2 A visual project timeline showing some key activities, project deliverables (PD) and milestones



At the start of 2020, three chief investigators (Kotlarewski, Power and Ozarska) the technical officer (Tanton) and research assistant (N. Nolan) left or took leave from the project. Two new co-leads joined the project (Wallis and Sawyer) and the PhD student (Millaniyage) arrived from overseas just before the Australian borders closed for Covid-19.

During this period the project scope was refined due to change in personnel and skills, and time lost due to lockdowns, and supply chain disruptions. As a result, the project focused on a new engineered flooring product using plantation resource which was the focus of the PhD project, as well as investigating interior lining opportunities with shorts using advanced manufacturing techniques. These are shown in Figure 3 with the arrow boxes. Further complications and delays continued at the end of 2020 with the loss of project staff (Sawyer and Lee) and restricted access to laboratory facilities in Launceston and Melbourne over first half of 2021.

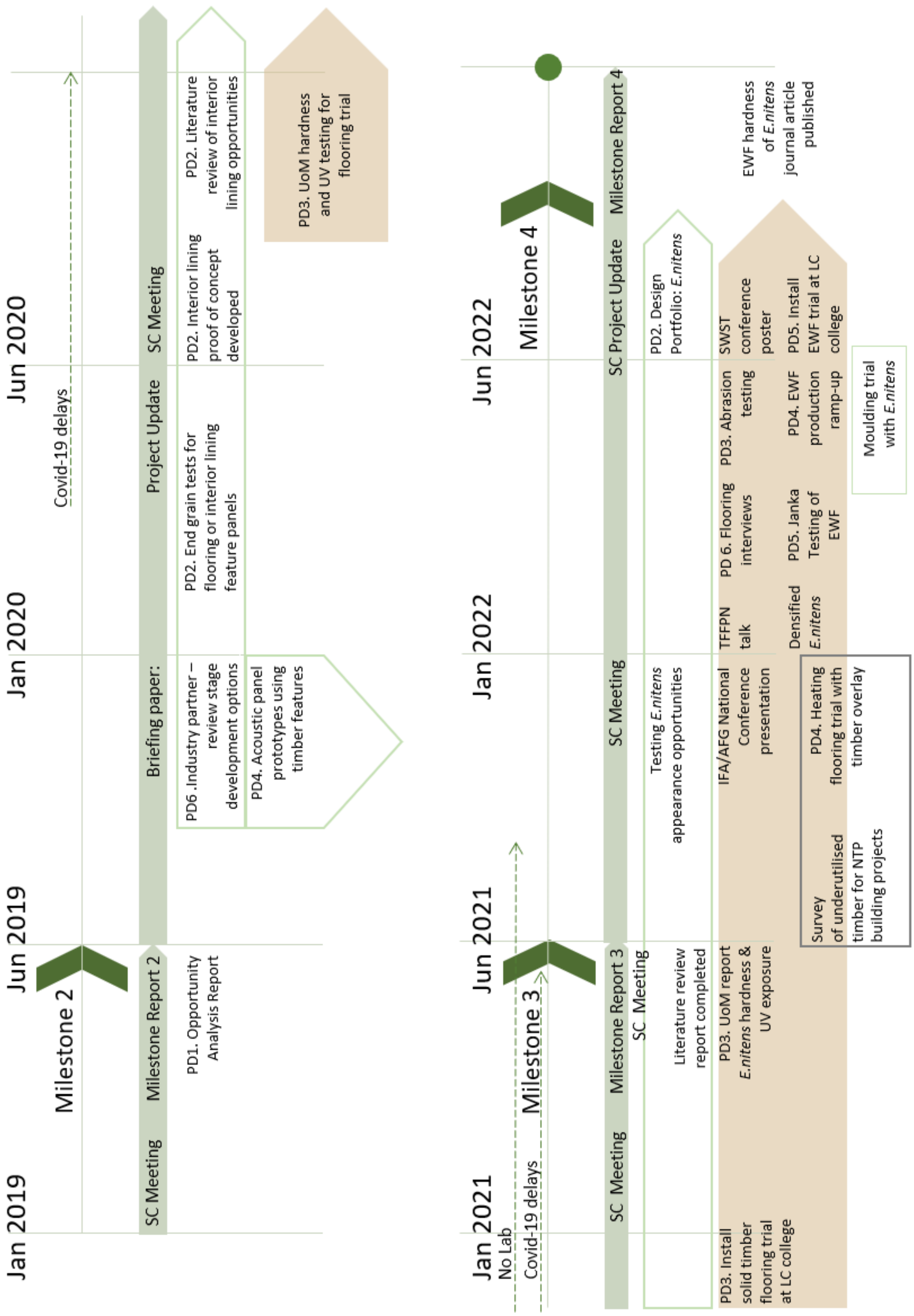


Figure 3 The project timeline showing key activities, project deliverables (PD) and milestones

Work on interior lining prototypes also ceased with the launch of Evove system (2022), a very similar proposition already developed and in production. Evove uses shorts and offcuts from furniture manufacturing to make new interior panels that can push mount onto a wall system. The timber by-products are straightened, dressed and laminated together, and then cut with a 5 axis CNC machine according to the design. A number of well-known furniture designers have contributed to the Evove series. It was showcased in the Tasmanian Timber display at Equinox Evolution Melbourne event in June 2022 (Figure 4).

Figure 4: Evove's Liminal tiles by Jon Goulder as the back wall for Tasmanian Timber display

Figure 2 captures that the volume of work and outcomes ramped up in the second half of 2021: with a new workshop manager and facility, heated timber flooring opportunity for the Northern Transformation Project (NTP) buildings, and the return of Kotlarewski from industry. It is evident with the return of the workshop, technical support, and industrial design co-lead, Kotlarewski that delayed work on the engineered flooring and interior lining opportunities occurred (Design Portfolio, separate attachment due to its layout).

This report now presents these four key components that took place after Milestone 3 report, the production ramp-up and industry trials in flooring.

New flooring research and development component

As stated, a new opportunity and impetus to include a commercial Tasmanian timber flooring product for the proposed River's Edge & Willis St buildings being built for UTAS's Northern Transformation Project (NTP) arose during the project. The project team worked with Industry partners in 2021 to investigate the performance of strip timber flooring on a heated subfloor. The following provides a summary and more detailed report is in Appendix A.

Strip timber floor performance on heated subfloor

The construction and monitoring of a Tasmanian hardwood strip flooring and plywood system installed over a hydronic heated slab began on October 8 till December 17, 2021. Additional observations were made on the floor performance at the end of the summer break on January 11, 2022. The objectives were to determine:

- If the prototype system is fit-for-purpose for proposed University of Tasmania (UTAS) and similar commercial building projects.
- The performance of four Tasmanian hardwood species as part of a strip flooring system installed over a heated slab.

The tested prototype system was designed to be builder-assembled from Tasmanian-produced solid timber boards and hardwood plywood. It was one option for the atrium floor in the River's Edge & Willis St buildings being built for UTAS's Northern Transformation Project (NTP). UTAS had a preference to use Tasmanian made products in these buildings' internal surfaces. However, uncertainty exists about the performance of a conventional overlay flooring installation on a heated slab. To address this uncertainty, a suitable prototype system was proposed, assembled and tested to determine if it was fit-for-purpose.

Fairbrother Construction, the builder for both the River's Edge & Willis St buildings, provided the details for and installed the slab and heating system. The research team specified and secured the timber for the floor systems, and Fairbrother contractors installed the system using standard industry practice.

Methodology

Establishing the heated subfloor

Fairbrother constructed a nominally 4.8 m long x 2.7 m wide section of heated floor in the enclosed annex of the UTAS's School of Architecture and Design building at Inveresk. This floor matched the detailed design for the floor for both NTP buildings as closely as possible. The floor was constructed with hydronics, and control system installed (Figure 5), the slab conditioned, and the flooring installed by 30 September 2021. As the floor received no direct sunlight, the heated slab and surrounding air governed its temperature.

Specified timber overlay system

- The preferred prototype system was 85 x 19 mm secret nail profile solid timber boards glued (Bostik Ultraset SF flooring adhesive) to a 9 mm hardwood ply substrate, directly fixed to the slab over a moisture barrier. The design of this system drew from earlier research findings that included a Tasmanian hardwood floor (*E. obliqua*) over a heated surface (Farrell & Gadient, 2009), including: A plywood substrate was preferred to direct stick of boards as it provides dimensional stability and a buffer to any thermal shock from the slab.
- An 85 mm wide board limits individual board shrinkage with changing MC conditions.
- A 19 mm board was preferred to a 12 mm board due to its increased stability with changing MC conditions. The thicker board also increased the floor service life.
- More relevant value for *E.obliqua* and *E.globulus* density and associated conductivity value of 0.180 (Farrell & Gadient, 2009, p.12)

The preferred species was a native forest Tasmanian blue gum (*E. globulus*) due to its density and ruggedness. Overall, three species were included in the prototyping to generate comparative results and additional options for the NTP projects and for industry. These were *E. nitens* (plantation) and *E. globulus* (plantation and native forest) and *E. obliqua (native forest)*.

Nominally 1 m wide panels of each of the four species was installed on the slab.

The system selected for the NTP project had a design calculated R-value of 0.162 with further analysis of the test results, the actual calculated R-value was 0.150 (Refer to Appendix A for details).

Instrumentation and monitoring

System instrumentation included temperature sensors in and on the slab and timber floor, a temperature and humidity sensor over the floor and timber sample boards (Figure 6). From 8 October, the hydronic control temperature was raised from 20 to 30 ºC in 2-3 ºC increments fortnightly. This was increased to 35 ºC on 13 December and 39 ºC on 17 December 2021 before being reduced to 20 ºC on 12 January 2022.

During this period, the sensors recorded temperature every 10 minutes and the floor moisture content (MC), and condition was monitored three times a week.

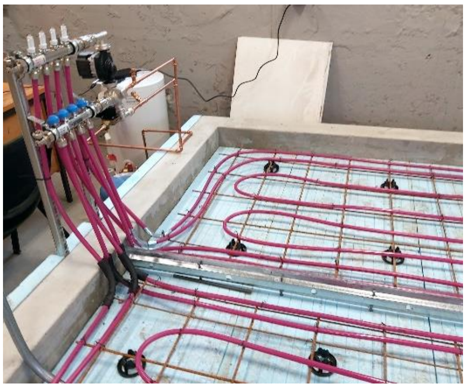


Figure 5: Base slab and hydronics

Figure 6: Completed floor and enclosure

Results

During the test period from October 8 till December 17, 2021, the top of the slab temperatures rose by 10.6 °C from 19 to 29.6 °C while the underside of the timber temperatures rose by 8.6 °C from 19 to 27.6 °C. See Figure 7. During the period to December 3, the timber's MC reduced gradually from an average 9.5% when first weighted to an average 9.1%. See Figure 8. Notwithstanding these changes, the system performed satisfactorily. Very few discernible gaps developed and there was no apparent loss in board stability or flatness. Hence, no cupping measurements were taken. Slight shrinkage was detected at several locations in the floor for all species on 11 January 2022, after the hydronics control was set to 39 ºC on December 17 and the surrounding room was closed for the Christmas lockup.

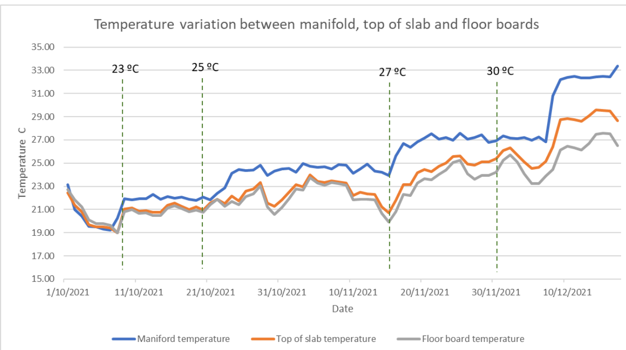


Figure 7: Temperature of the manifold, top of slab and under the floor boards over time

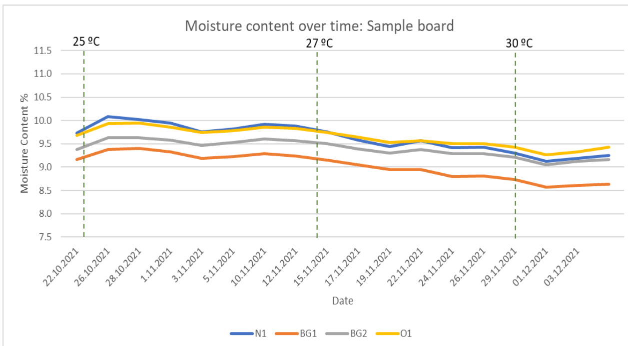


Figure 8: Moisture content variation assessed by sample board – 22/10/21 – 3/12/21

Discussion

If laid at the correct MC (which includes acclimatising the timber in the room prior to installation), the specified system's stability appears to be fit-for-purpose for all species during the floor's winter heating cycle.

Additional monitoring and data assessment is required for:

- Temperature cycling between winter and summer conditions.
- Overall thermal, MC and stability performance.
- The thermal lag between hydronic input and temperature output through the floor.
- The impact of direct sunlight on the floor in addition to the overall timber hydronic flooring system.

See appendix A for the full report.

Innovation Award

This research work has led to a Tasmanian flooring product to be specified and installed into the River's Edge & Willis St buildings for UTAS. It provided the evidence and confidence for UTAS to employ a new system using Tasmanian materials (board and plywood) for a commercial application, which otherwise would not have been possible. UTAS preferred to use a locally made system than the few Australian options, as most commercial products come from overseas.

Recently, the UTAS Vice Chancellor's Innovation Award 2022 was presented to the research team in recognition of their work to drive change and contribute to economic prosperity of the state and industry partners.

Industry flooring application interviews: Architects, Industry Partners and Experts.

Introduction

A series of interviews were conducted with several industry partners, architects, and experts in the field of timber (n=18). The purpose was to gather insights to develop engineered flooring prototypes using *E. nitens*. A 30-minute interview with structured questions was conducted with each participant. Although the sample size of participants is not statistically significant it is a purposeful sample to ensure a good array of perspectives and information to inform the design process. There were four experts from the timber flooring industry, four industry partners (some interviews consisted multiple participants from the same organisation), and six architects who typically use timber flooring (two Tasmanian based, two Victorian based and two from New South Wales) participated in the interviews. Out of the architects interviewed, two focused on high end residences while the rest had experience in specifying for both domestic and commercial applications. Majority of the participants had closer to or more than a decade, of experience in their profession or timber related industry (Figure 9). Only Industry partners 4 (IP4) are relatively new to the field, and it is indicative of the skill shortage occurring in the timber industry and others.

Figure 9: Overview of participants' experience level in their profession or timber related industry

Summary of key points from the interviews

Table 2: Summary of interviews with Architects (AR), Industry Partners (IP) and Timber Experts (EX)

Overall concern of participant categories	• IP - identifying new timber resources for flooring applications that may have lower densities than current products. • EX – awareness that current Australian standards and flooring guidelines are not fit for the purpose of plantation resources. • AR – sourcing and understanding product information related with environmental impact, cost and aesthetics, interested in comprehensive data sheets, green credentials.
Influence of local markets on product selection	Through participants descriptions of preferred timber flooring products, it was evident that these varied according to their location and local market trends. For example, in Queensland there is a preference towards 19mm solid flooring as opposed to 12mm overlay. • In Victoria and Tasmania, the market ratio for flooring is around 70% for 12mm overlay and 30% for 19mm solid boards. • This is in contrast to Western Australia, Queensland and New South Wales market where the ratio is around 10% overlay and 90% solid flooring.
Species selection in relation to Hardness	• Hardness is used as a marketing tool in some states, however, in some markets such as New South Wales, lower density species are in demand due to people wanting to replicate the same species which has been installed in past applications. • Architects appeared to have limited concerns in hardness values as they usually specify timbers which they are familiar, with known performance for certain end use. • Architects working in the commercial arena had more knowledge or concern about hardness.
Flooring preferences	Engineered flooring seems to be still relatively new in Australian market, solid timber flooring is mostly preferred but engineered flooring has been more closely considered recently with less product availabilities due to construction demand.
Use of plantation timber	IPs and EXs are: • Keen to see plantation timber entering the flooring market but at present they are not clear as its performance and serviceability is still unknown. • The thinned and pruned plantation resource is considered to be more favourable as it has lesser knots, however, in general there seems to be a desire for featured and light-coloured timbers ARs hinted that they are not convinced of ethical/chain of custody details of Australian timbers (for example timber imported from Europe or America is stated to have data sheets with details required to easily specify the timber for projects)

These interview findings helped inform the product development process for developing a new engineered flooring application for in-state manufacturing. While solid 19mm boards have traditionally been favourable and will always have a market share the desire and new trends for 12mm overlay flooring will inevitably grow to stretch available resources in innovative ways. The following section details the type of engineered flooring products that were developed, manufactured locally with industrial processes and equipment and finally installed in a commercial environment for monitoring and evaluation.

Production ramp-up

The journey of developing an engineered appearance flooring wood product for in-state manufacturing was informed by the original opportunity analysis report (part of Report 2). Consideration was given to the availability of resources and existing infrastructure to manufacture a flooring alternative at an entry level of investment. In addition, a literature review of timber properties and performances were benchmarked against contemporary resources available which were also tested for several key properties.

Determined to identify a range of product options for key species such as plantation *E. nitens* and Tasmanian Oak, the design process broadened the alternative product offerings to better utilise, extend and re-purpose these resources in Tasmania. The configuration of the engineered flooring and its system level breakdown highlighted several compositions that incorporated traditional timber boards, veneer, plywood and modified timber by thermo mechanical densification (See NT014/ NIF Final Report for thermo mechanical densification (Wood et.al., 2022)). These various compositions were prototyped to determine baseline performances such as stability, machining tolerances, the installation technique and supporting systems and services required to maintain the product in service for longevity.

Background

As previously highlighted the focus of this report is to demonstrate the production ramp-up phase of developing an engineered appearance flooring wood product. Early in the project, a traditional floor comprising of several species was laid to determine a baseline performance for acceptable timber flooring at a commercial site in Launceston (Figure 10). This was done as part of the planning phase in preparation for a comparative study against any new products developed from this project.

Figure 10: Traditional floor laid as a control

Over a year the flooring was monitored for indentation, markings, significant movement and general wear and tear. Full details of this traditional floor are described in Report 3.

Flooring concepts

In-keeping with the opportunity analysis (Report 2), and to determine the opportunities surrounding engineered wood flooring products for in-state manufacturing several concepts were identified for production ramp-up. The following, Table 3 describes the flooring compositions tested.

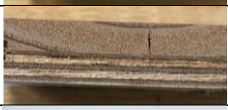
These tests were based on local timber industry interests and existing capabilities and equipment. A round of discussions conducted with industry, architects and flooring specifiers supported in identifying the design requirements, flooring trends and current demand.

A core consideration of this developmental work was to demonstrate the use of plantation *E. nitens*, in particular:

- Fibre managed boards with a diverse range of natural features,
- Sawlog managed boards as clear grade
- Sawlog managed veneer (these are not intended for market, but industry partners are keen to know its performance properties using existing manufacturing processes)
- *E. nitens* plywood

Additional Tasmanian Oak overlay flooring and a Tasmanian Oak engineered floor were used as a control to determine the difference between these concept tests and market accepted products.

Table 3 Concept details produced in the production ramp-up phase

Flooring Type	**Image**	**Description**	**Layer Thickness (mm)**	**Nominal cross section size (mm)**
Sawlog *E. nitens* Marine plywood *E. nitens* veneer		Top layer Core layer Backing layer	6.00 6.00 0.6	12.6×85
Fibre *E. nitens* Marine plywood *E. nitens* veneer		Top layer Core layer Backing layer	6.00 6.00 0.60	12.6×85
Sawlog *E. nitens* Marine plywood		Top layer Core layer	6.00 6.00	12.0×85
Densified *E. nitens*		One layer	12.00	12.0×85
E. nitens veneer Marine plywood *E. nitens* veneer		Top layer Core layer Backing layer	1.20 12.00 0.60	13.8×85
E. nitens veneer Fibre *E. nitens* plywood *E. nitens* veneer		Top layer Core layer Backing layer	1.20 12.00 0.60	13.8×85
Solid *E. obliqua*		One layer	12.00	12.0×85
Prefinished Tasmanian Oak Rubberwood (*Hevea*)		Top layer Segmented core	3.20 11.0	14.2×165

Industry production

The following images demonstrate the manufacturing process to construct the engineered appearance flooring wood products at an industry partner's operation. The manufacturing process comprised of:

- Glue application (PVA glue with heat and water resistance conforming to EN 204-Group D3)
- Panel sorting and layup
- Pressing and glue curing, and
- Panel sanding

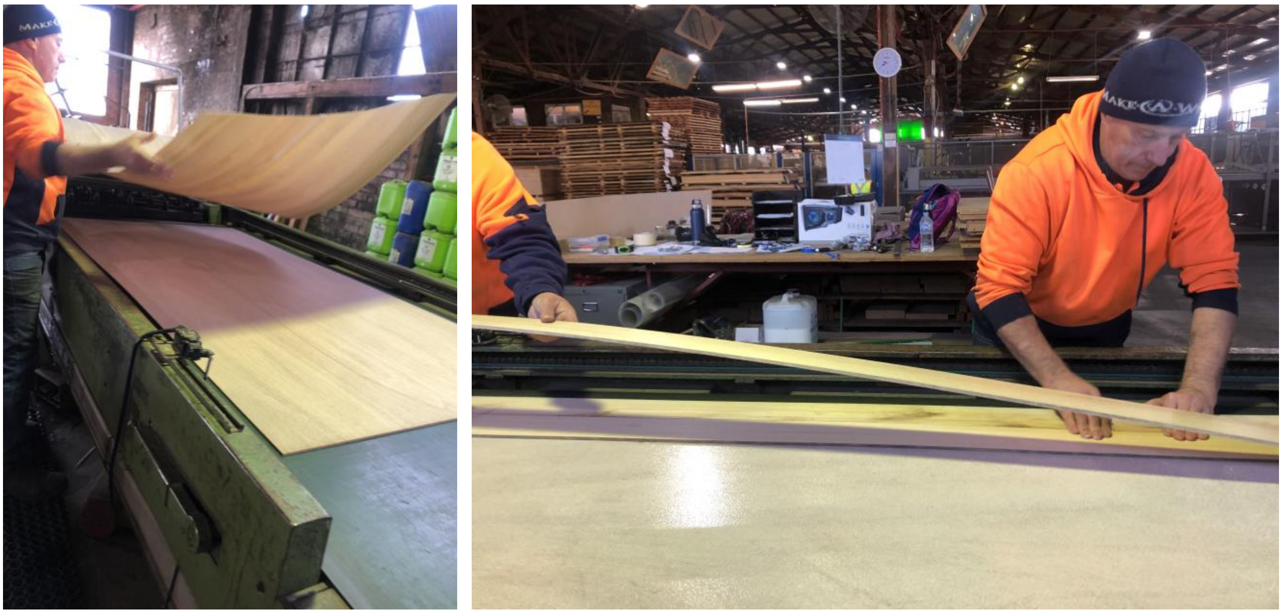


Figure 11: Glue application and engineered appearance flooring layup- the solid boards were dressed to 6mm at CSAW workshop and transported to the production facility, the veneers with 0.6 mm default thickness used for the concepts were randomly obtained from the commercial production line of the facility. 1.2 mm top layer of veneers were obtained by gluing two 0.6 mm veneers together.

Figure 12: Post glue curing for fibre managed concept- PVA glue (water resistant) was subjected to hot pressing, all concepts showed good adhesion.

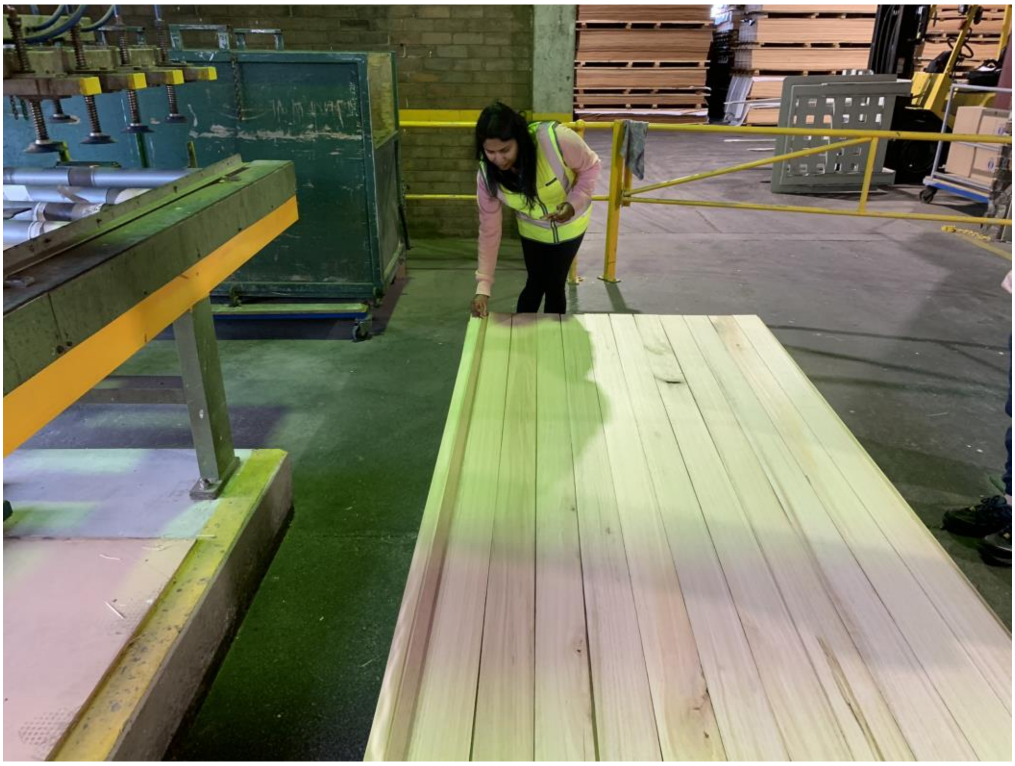


Figure 13: Post glue curing for sawlog managed concept: gaps were kept between each top layer board through the gluing process to plywoods to facilitate the ripping of panels.

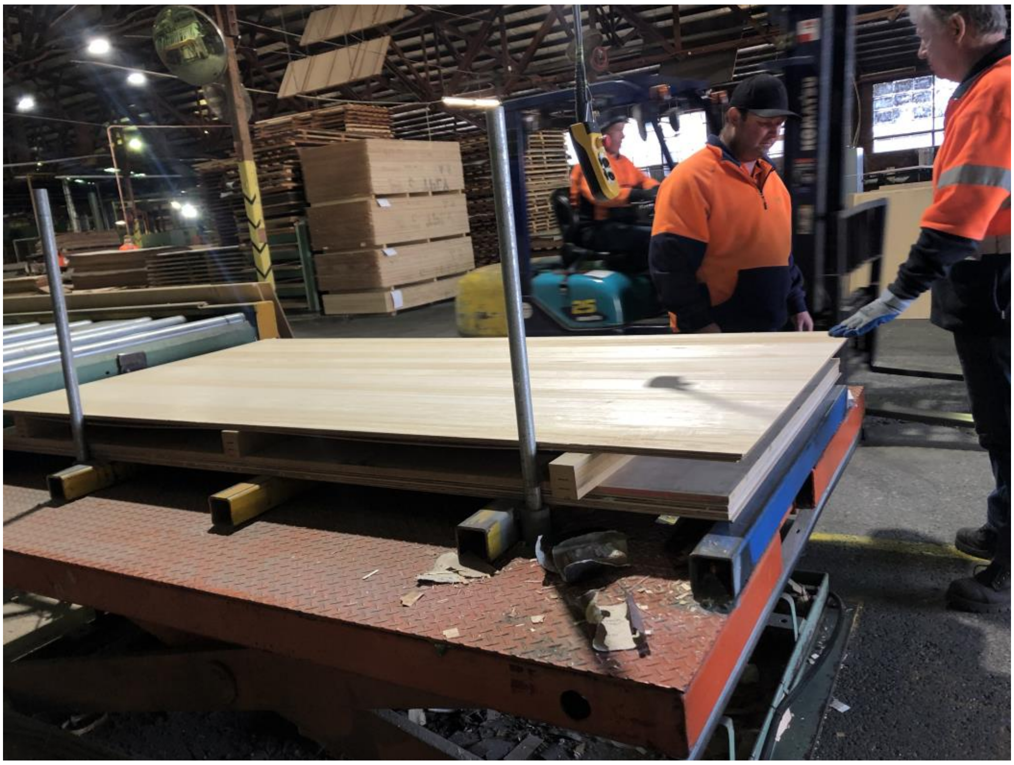


Figure 14: Post sanding for veneer concept**:** Panels with *E. nitens* plywood showed more consistency in thickness than the marine plywood used as observed in the sanding process.

Secondary processing

After the core manufacturing of the various concepts on an industrial site a regime of secondary processing was employed to manufacture single overlay lengths of the engineered appearance flooring wood products. Ultimately the entire manufacturing process would be conducted on an industrial scale however, for the purpose of validating the concepts manufacturing process, appearance and performance, a slower bespoke process was employed in a controlled environment to finalise the overlay flooring.

Figure 15: Ripping panels into single overlay lengths at CSAW workshop.

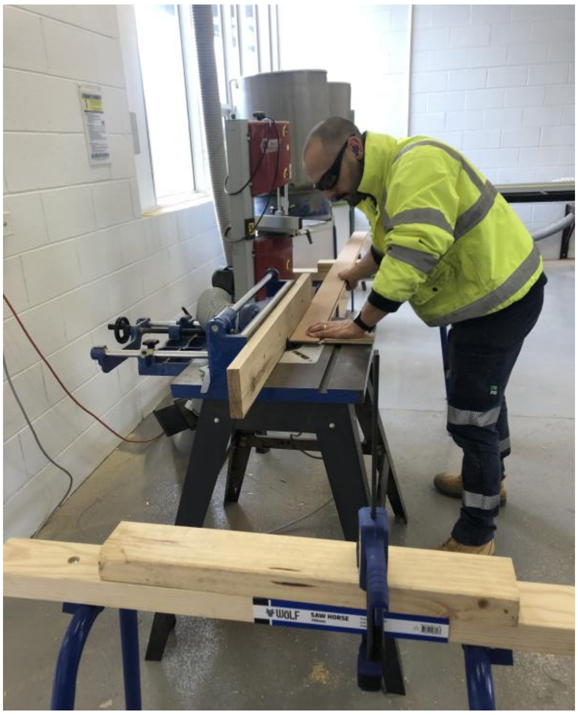


Figure 16: Profiling concepts with Tongue and Groove (T&G)

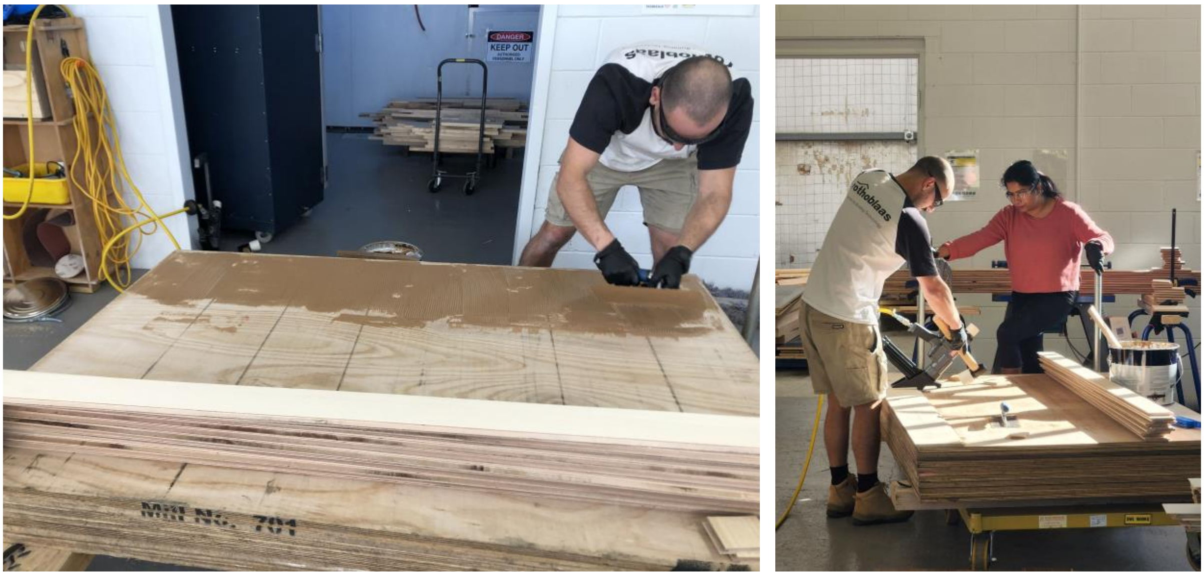


Figure 17: Applying flooring adhesive and secret nailing the concepts to a structural plywood as per standard installation-the same procedure used in preparing the solid flooring panels for previous trial was adhered. This allowed for comparisons of the machinability, workability aspects of each concept which was documented. The only exception being the densified *E. nitens* panels as they were brittle and required more attention through T&G and nailing process.

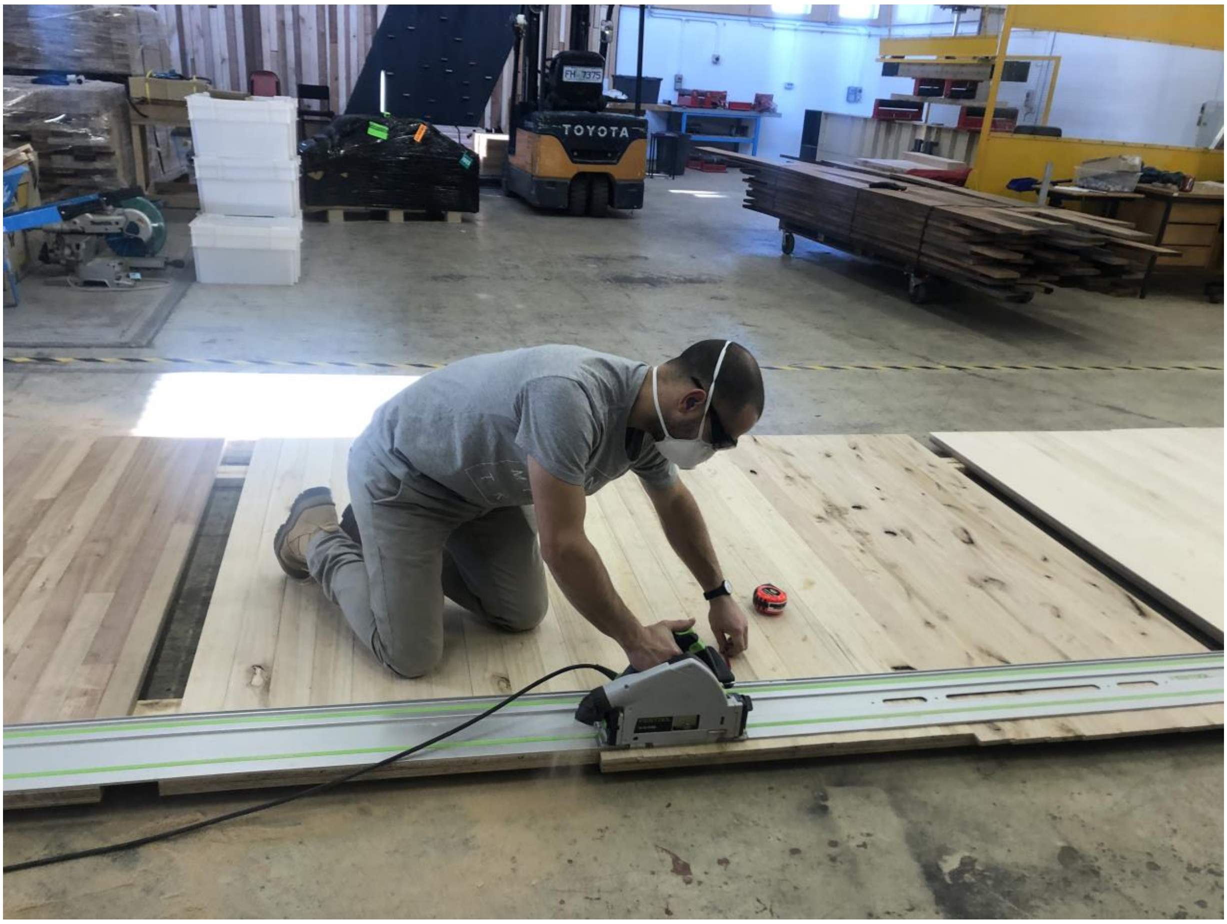


Figure 18: Squaring the final concepts prior to commercial site installation.

Figure 19: Panels with clear sealant (Urethane two-pack polyurethane waterborne coating system with a satin finish adhering to general industry practice) prepared for installation at LC college.

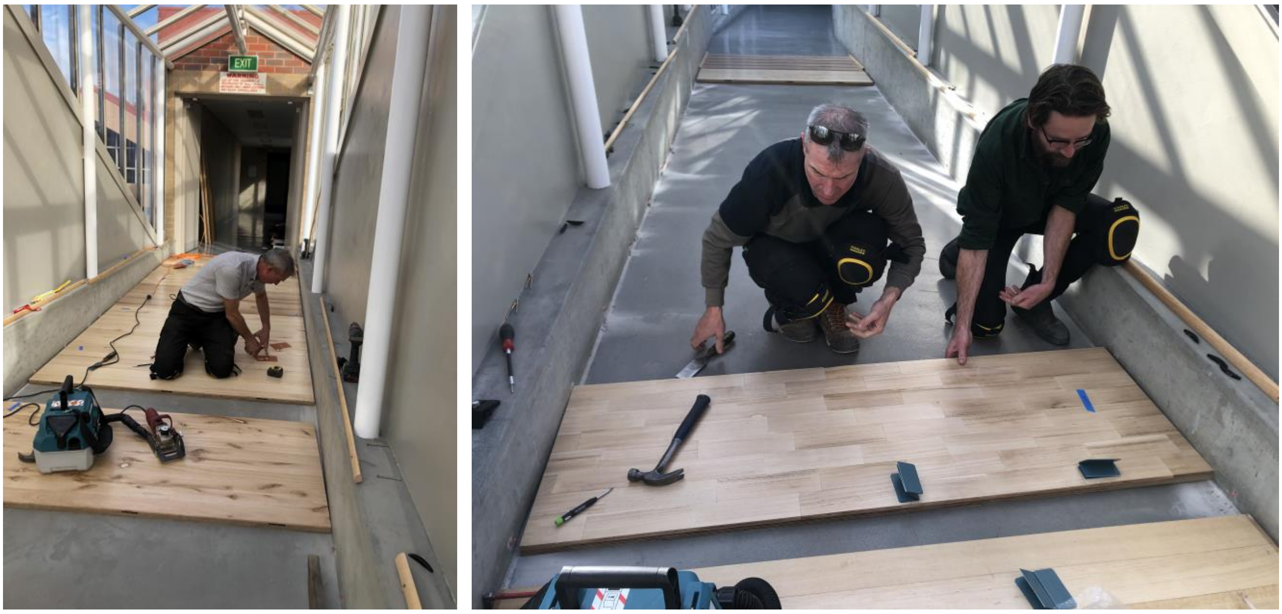


Figure 20: Concepts being installed on commercial site: same venue and installation practice used for solid flooring trial was replicated.

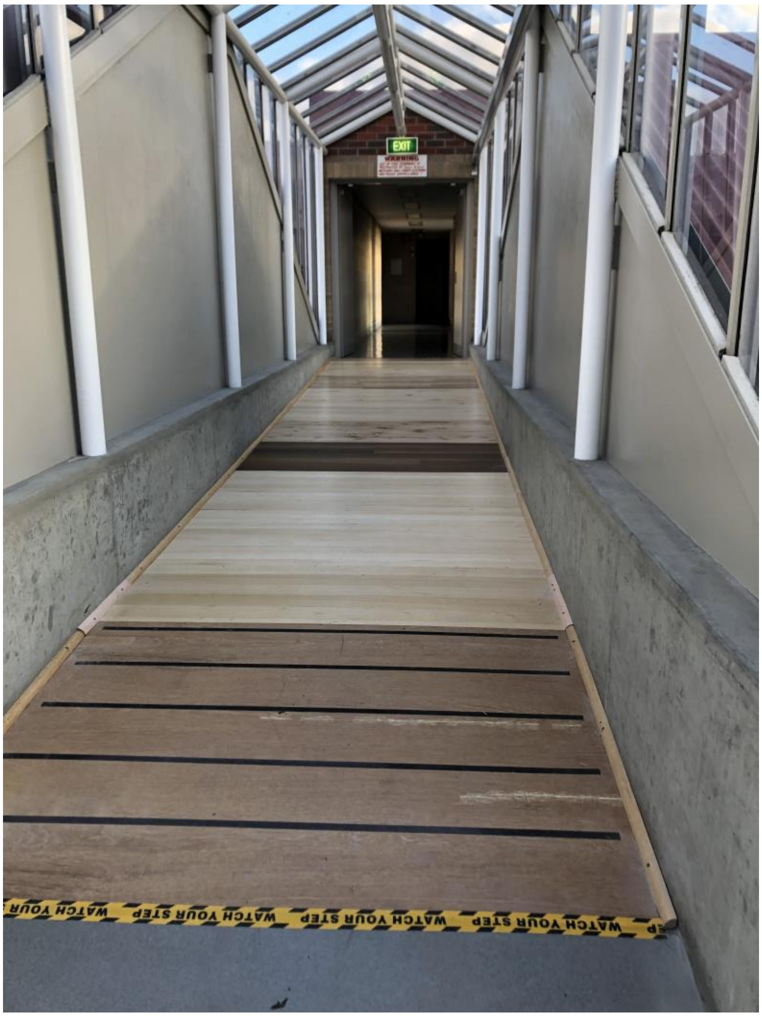


Figure 21: Concepts installed on site and ready for one-year trial.

Ongoing monitoring and validation of the presented concepts will be reported beyond the scope of this project. This flooring trial is part of Ms Kuluni Millaniyage's higher degree by research project at the University of Tasmania. Beyond the life of this project Kuluni will be investigating the difference in performance between the original solid board trial and this engineered appearance flooring trial. The in-service performance of solid board trial and engineered floorboards will be compared based on visual observations of stability, colour variations, resistance to indentations and abrasion in an environment exposed to sunlight and high levels of traffic. Furthermore, laboratory analysis of hardness and abrasion resistance of developed engineered concepts and solid boards will be used to understand material properties, possible improvements and validation. Further results including a true comparison to the performance of the flooring trials will be published after the conclusion of this project.

Some preliminary results have been recently published in the *Buildings* journal with the title, Janka Hardness Evaluation of Plantation-Grown *Eucalyptus nitens* for Engineered Flooring Applications (Millaniyage et. al., 2022).

Post production ramp-up testing

Abrasion Resistance Testing of Plantation *E. nitens* and Regrowth Forest *E. obliqua*

The review of literature and international standards into engineered wood flooring products identified an abrasion resistance test used in European standards (EN). The test was conducted using Taber Abraser method as specified in EN 14354:2016: Wood-based panels - Wood veneer floor coverings (Annex E: Determination of abrasion resistance using the sandpaper method). Both sawlog managed *E. nitens* and fibre managed *E. nitens* were tested along regrowth forest *E. obliqua* which is currently available in the market place. The test was performed on 15 samples of each feedstock. Density and moisture content were also calculated from samples obtained from the same boards used for abrasion resistance determination. This report consists of preliminary results and more sample testing will be conducted in future to obtain better understanding of the tested properties.

Methodology

	Elements tested
Species	Sawlog *E. nitens*, Fibre *E. nitens*, *E. obliqua,* and a commercial Tasmanian Oak engineered flooring product with UV cured coating as a control
Types of Tests included	EN 14354:2016: Wood-based panels - Wood veneer floor coverings (Annex E: Determination of abrasion resistance using the sandpaper method) AS/NZS 1080.1:2012 Moisture content AS/NZS 1080.3:2000 Density
Test element size	Round timber disks with 100mm diameter and 5 mm thickness (Figure 20)
No of elements tested	15 on each timber type, except 5 times on the control samples
No of elements discarded	Nil
No of elements included in analysis	15 on each timber type, except 5 times on the control samples
Notes on elements and their preparation	Sawlog *E. nitens* and *E. obliqua* obtained (quartersawn) from Britton's Timbers and fibre *E. nitens* from CUSP (back sawn), and commercial engineered flooring product from Neville Smith Forest Products.

	Testing procedures
Testing conducted	Tests were conducted at CSAW T40 workshop (UTAS) between August-September 2022. The methodology in the standard was adapted to facilitate the testing of solid timber specimens.
Testing equipment	Testing was conducted on Taber Abrasion machine purchased by project grant funds for the purpose of validating the level of abrasion for comparison among different timber species and to EN 13329:2016, Annex F. The wheels of Taber Abraser were adjusted so that each wheel exerted a force of (5,4 ± 0,2) N on the test specimen.

Testing method	Round specimens with 5mm thickness were prepared using a hole-saw and allowed to stabilise for two weeks. After weighing and measuring the thickness at 4 points, the specimens were clamped into the Taber Abraser and subjected to abrade with S-42 grade sandpaper with approx. 60 min-1 for 1,000 revolutions. The decrease in thickness by abrasion was determined using a micrometer. The percentage thickness loss was determined for each specimen and an average was determined.
Additional tests	Moisture content was determined in accordance with AS/NZS 1080.1:2012 for all specimens. Density was determined in accordance with AS/NZS 1080.3:2000 for all specimens.

Sawlog *E. nitens* (quartersawn)

Fibre E. nitens (back sawn)

E. obliqua (quartersawn)

UV coated engineered panel

Figure 22: Tested samples showing the abraded wheel pathway

Results

Density and moisture content

The results of moisture content and density assessment in accordance respectively with AS/NZS 1080.1:2012 and AS/NZS 1080.3:2000 is shown in Table 4.

Table 4: Density and moisture content of samples

	Sawlog *E. nitens*		**Fibre *E. nitens***		***E. obliqua***	
	Density (kg/m3)	MC%	Density (kg/m3)	MC%	Density (kg/m3)	MC%
Mean	645	11.6	500	10.8	695	10.4
SD	77.15	0.93	51.24	0.53	73.89	0.48
Min	460	9.7	445	9.6	560	9.5
Max	745	12.9	630	11.8	835	11.2

Abrasion Test

The thickness loss resulted by the test and the abrasion percentage is summarised in Table 5.

Table 5: Abrasion resistance testing of specimens

Abrasion as a percentage of thickness loss (%)	**Sawlog *E. nitens***	***Fibre E. nitens***	***E. obliqua***	***Commercial engineered flooring with Tasmanian Oak top layer***
Mean	3.75	5.59	3.28	4.33
SD	0.0106	0.0107	0.0095	0.0157
Min	1.96	3.82	1.98	1.75
Max	6.01	7.25	5.34	6.13

Discussion

The results of abrasion test showed that fibre managed *E. nitens* showed higher abrasion when compared to sawlog *E. nitens* and *E. obliqua*. The abrasion observed in sawlog *E. nitens* was similar to *E. obliqua* and lesser than the Tasmanian Oak engineered flooring control. Testing of more samples is recommended for statistical comparisons of the data as only 15 samples for each timber type, except 5 samples for the control were available for testing Published data on abrasion resistance testing of Australian timbers using the followed approach is not available in literature to the authors' best of knowledge. Therefore, testing a variety of commonly used flooring timbers for comparison purposes is also recommended. Further testing would also require testing finishing systems and their performance on the different timber species.

Conclusions and recommendations

At the end of this report the following conclusions were drawn from the four components:

Strip timber flooring on a heated slab

Preliminary testing of 19mm Tasmanian hardwood boards, including plantation *E. nitens* (sawlog and fibre managed) and *E. globulus* with native regrowth *E. obliqua*, to 9mm hardwood ply substrate has shown no apparent loss in board stability or flatness when tested on a heated slab trial. The strip flooring was directly fixed to the slab over a moisture barrier. The temperature range of the heated slab that was observed during the trial began at 20 ºC to 39 ºC, over a two and half month period. The trial has led to sufficient confidence in using Tasmanian board flooring for the NTP building by UTAS, the architect and the builders. The product selected has a calculated R-value of 0.150, which was considered acceptable by the architects and clients. The use of a Tasmanian floorboard in a commercial application on a heated slab is a new market. There are very few products if any Australian flooring products shown to perform on a heated slab reliably and specified. Further observations are to be made of its in-service performance.

This work can be further developed by observing the in-service performance in the new River's Edge building on the UTAS campus in 2023. This will allow a better understanding of its performance over the winter and summer conditions. It will also provide more information on the impact of sunlight and daylight on the floor. As this is only one species selected there is also more work to be done with the remaining species.

Industry flooring application interviews

The interview process confirmed the literature review and opportunity analysis that there are few standards or guidelines in Australia to assist in the specifying appropriate flooring products and their physical properties. Reference to current timber flooring in the Australian standards refers to a traditional application across floor joists and does not include direct stick practices to a concrete slab or the application of an engineered timber floor. Some of these can be found in industry guidelines, however, as the interviews showed, the location of the architect, client or project can influence the product selection. Variations may occur across many factors such as board thickness, overlay, timber species colour and cost, labour, final finish, hardness and environmental credentials.

Even from a small survey of architects, industry partners and timber related experts there were different concerns and motivations when asked about the potential of future timber flooring product:

- Industry partners were concerned about applicability of plantation resource for flooring as the Janka hardness will be lower than current native regrowth products. Past experiences suggest that Tasmanian species are sometimes overlooked in the mainland markets as it Janka hardness is lower.
- Experts highlighted the lack of knowledge and comparison tools/ standards with engineered flooring products whether they may be imports or produced locally.
- Architects were less persuaded by the sole factor of a species Janka hardness – it rose in importance with a commercial application. Many architects were interested in the providence and environmental credentials of products. A few indicated they had greater ease and confidence from using an EU based product.

Overall, there was no significant barriers to the acceptance of a lower density plantation-based flooring product if it was made locally for a domestic application that has similar properties to Tasmanian Oak flooring.

Engineered timber flooring ramp-up

The prototyping of an array of engineered timber flooring panels using different thickness of plantation *E. nitens* (sawlog, or fibre) top layer with different substrates and backing layers show that there are number of options that can be locally manufactured with existing infrastructure and capabilities. In addition, these are tested alongside a solid 12mm overlay *E. obliqua* board, 12mm thick densified *E .nitens* sawn board and existing commercially engineered Tasmanian Oak flooring product. Results thus far showed that all materials adhered well during the production process. The densified *E. nitens* sawn boards are difficult to machine profile and install due to their brittleness. The results of this trial are to be reported in 2023 as it will have been installed for a year. Initial results are positive.

Engineered timber flooring post production testing

The abrasion test is a novel test in Australia for testing timber flooring products. This project has tested *E. nitens* (sawlog and fibre), *E. obliqua* (one of the key species used in Tasmanian Oak) and commercially produced engineered flooring out of Tasmanian Oak with a UV cured coating. It showed that the amount of abrasion as a percentage of thickness loss was comparable between sawlog E. *nitens* and *E. obliqua* samples. There was increased loss in the commercial product and the fibre *E. nitens*. This indicates that plantation sawlog *E. nitens* performs well in terms of abrasion to existing species. There also appears to be an increased thickness loss in the commercial engineered flooring product, it is unclear the role of coating here or if the abrasion level is similar when tested with no coating. Coating formulation can include additives such as titanium oxide to improve wear resistance, it is thought that this type of coating would improve abrasion results.

As there are no other values existing on Australian timber species and those used in flooring whether it be engineered or solid – this test and the need to investigate more species is an important next step. There is likely to be more engineered flooring products entering the Australian market due to the restriction to native log supply.

Other project findings and recommendations

In addition to the findings reported above, the following highlights earlier report findings and the resulting project recommendations:

Report 2 indicated that there are many new opportunities for hardwood appearance products. From this opportunity analysis, key areas identified to expand and optimise the use of hardwood timber with in-state manufacturing included: engineered flooring, novel interior linings that take advantage of using shorts and offcuts from processing, using feature in the timber as a positive design generator and the opportunities presented by using parametric design tools with a CNC flatbed router to modify the surface and patterning of timber.

Report 3 described the method and outcomes of:

- In-service timber flooring board trial comparing *E. nitens* (fibre and sawlog) with a number of existing species used in flooring. This involved testing the properties of *E. nitens* with a control *E. obliqua* – UV weathering, hardness, density, shrinkage and the in-service performance of the boards during and after the trial. Current Australian standards and guidelines for flooring were also compared with other international standards to better understand what makes for a good or acceptable domestic or commercial floor.
- End-grain experiments for flooring (*E. nitens*) or interior lining (Tasmanian Oak) panels
- High-value acoustic cassette prototype
- Literature review: Investigating the viability of prototyping modular/panelised wall/ceiling lining systems in Tasmania.

Key findings and recommendations from Report 3 indicate that there are opportunities for:

- *E. nitens* to be used in engineering flooring products in a domestic application. When compared to the control *E. obliqua* there was not a significant difference with the sawlog *E. nitens* in the in-service trial.
- Updates to existing Australian Standards and guidelines for timber flooring in terms of performance indicators, application use and other possible parameters to demonstrate appropriate timber floor species and product types (i.e. engineered products).
- End-grain applications with shorts to make interior lining and other products, but it would require a dedicated glue-line and sufficient volume of shorts. It is unclear whether this option is feasible when finger jointed shorts to produce structural members are in demand for building.
- The high value acoustic cassette is viable, but it is more likely to take the form of mismatched veneer with features applied to a substrate. The features are celebrated by the hole patterning occurring around it which is relatively easy to employ on a CNC flatbed router. More testing with a joinery company and an architectural practice may generate more development.

- Use of parametric design scripts to easily work with random featured veneers or boards – to make the feature into an asset and a part of the story of the material.

Overall, the NT015 / NIF079 project has developed several prototypes, design ideas and concepts that have increased familiarity and confidence in the suitable uses, properties, and processing of plantation *E. nitens* (sawlog and fibre) by industry and research partners. In addition, the project has allowed a new grouping of foresters, scientists, timber processors, researchers, and designers to develop and establish trust in Tasmania. There is now a better level of understanding of what is involved from the tree to the log, to the timber board and products. The greater NIFPI projects in Tasmania has also afforded the expansion of research skills and capabilities for the local forest and wood products section through training part of the next generation through higher degrees such as PhDs and mentoring tenured UTAS staff.

There are many future opportunities for lines of investigation and design work to assist in-state product development. In part, some of these areas are in response to the infancy of engineered products and processes involved. The other part is the on-going need to build skills and capabilities in the industry and research. Future areas identified from NT015/NIF079 project are:

- Evaluating the performance of different coating systems have on engineered timber flooring, in particular lower density plantation resources.
- Testing alternatives to the use of formaldehyde-based glues in plywood panels, interior lining products and engineered products due to concerns of indoor air quality.
- Better quantifying the volumes of off-cuts and residues produced in the state, to encourage other business opportunities or markets.
- Ways to improve market confidence and social license issues in specifying and selecting locally made timber appearance products when concerns and perceptions remain uncertain with local, native and plantation forestry management practices, timber processing, types of products and residues
- Ways to bridge the conceptual difference between producing sawn and veneer-based commodity products with engineered products and the use of advanced manufacturing tools.

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Dylan Gardner and Arishma Sami, casual research assistants (2022)

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Appendix A

Strip timber floor performance on heated subfloor NTP River’s Edge & Willis St buildings: Atrium floor prototype

This technical report describes the monitored performance of a prototype Tasmanian hardwood strip flooring and plywood system installed over a hydronic heated slab. It covers construction of the prototype and its monitoring as the floor was heated from October 8 till December 17, 2021, with additional observations on floor performance to January 11, 2022. This activity is a sub-project of the National Institute for Forest Products Innovation’s (NIPFI) project: *NT015/ NIF079: Developing a New Generation of Tasmanian Appearance Hardwood Products for In-State Design and Manufacturing*.

The objectives were:

- To determine if the prototype system is fit-for-purpose for proposed University of Tasmania (UTAS) and similar commercial building projects.
- To determine and compare the performance of the four Tasmanian hardwood species as part of a strip flooring system installed over a heated slab.

Limits exist on research and practice around the use of timber strip floor in Australia’s non-residential building design and construction sector, particularly for installations over heated slabs. Forest and Wood Products Australia (FWPA) funded extensive work on timber floors in mainly residential construction in 2009 through project *PNA010-0708: Advanced research into floor performance issues*. While also mainly focused on residential construction, Part C of that project by UTAS’s Farrell and Gadient covered the effects of radiant under floor heating systems on floor performance in cool temperate climates.

In design practice, WoodSolutions currently distributes *Design Guide 9 Timber Flooring Design guide for installation,* based largely on the results of the 2009 FWPA work. However, no Australian flooring installation standard exists. In commercial project design, the availability of systems guarantees impacts specification. Timber strip floor producers generally provide standard *fit-for-purpose* guarantees on the performance of their products in projects, but tend to avoid explicit guarantees for builder-assembled solutions in specialist installations. This is largely because they have little control over the details of the products’ use in these systems on site. Some timber flooring products do have guarantees. However, these are often prefinished composite or engineered, ply-based products in a ready-to-lay configuration.

The prototype system tested in this sub-project was designed to be builder-assembled from Tasmanian-produced solid timber boards and hardwood plywood, and to be one option for the atrium floor in the River’s Edge & Willis St buildings being built for UTAS’s Northern Transformation Project (NTP). In addition to the increased ruggedness of a solid timber floor system, UTAS would prefer to use Tasmanian made products in these buildings’ internal surfaces if possible. However, uncertainty exists about the performance of a conventional overlay flooring installation on a heated slab. To address this uncertainty, a suitable prototype system was proposed, assembled, and tested to determine if it was fit-for-purpose.

Acknowledgements

This sub-project would not have been possible without the support of:

- The UTAS Northern Transformation Project team.
- The Fairbrother construction team working on the NTP projects.
- CSAW staff members, particularly Mr Stuart Meldrum and Ms Kuluni Millaniyage.

Methodology

Given the lack of practice guidance in Australia on the installation of timber strip floor over heated slabs, this sub-project’s methodology was largely based on:

- British Standard *BS 8201:2011 Code of practice for installation of flooring of wood and wood-based panels*
- The methodology deployed in *PNA010-0708* Part C.
- The system and construction details planned for the UTAS NTP buildings.

The methodology’s stages include:

- Establishing the heated subfloor.
- Preparing and installing the timber overlay system.
- System instrumentation.
- Monitoring the system's performance on a heated floor.

Fairbrother Construction, the builder for both the River's Edge & Willis St buildings, provided the details for and installed the slab and heating system. The research team specified and secured the timber for the floor systems, and Fairbrother contractors installed the system using standard industry practice.

The heated subfloor

Fairbrother constructed a nominally 4.8 m long x 2.7 m wide section of heated floor in the enclosed annex of the UTAS's School of Architecture building at Inveresk. See Figure 23. This floor matched the detailed design for the floor for both NTP buildings as closely as possible. It includes a base and edge slab, with a set down section of insulation, hydronic heating lines fixed to steel reinforcement, and a concrete topping.

In the prototype floor, the heating lines were connected to infeed and outfeed manifolds and an electric hot water system. A control system regulates water temperature and flow. See Figure 24. Once the heating system and associated sensor were installed and checked, the topping was installed. See Figure 25. The allowable tolerance on the flatness of the topping's surface was less than 3 mm across a 3 m straight edge.

As the floor receives no direct sunlight, the heated slab and surrounding air govern its temperature.

Figure 23: Heated slab with insulated forma, and hydronic heating coils attached to the reinforcement.

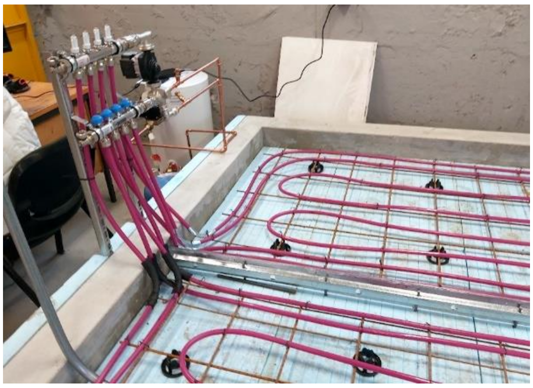

Figure 24: Hydronic heating manifold and hot water unit.

Figure 25: Topping to the heater slab

Figure 26: Builder measurement of slab condition

Slab conditioning

BS 08201 establishes a target moisture content (MC) of the slab of less than 3% and a relative humidity (ErH) of less than 75% prior to the timber's installation. It states that MC measurement can be taken 48 hours after any heating systems and dehumidifiers have been switched off, using a BS 8203 compliant hygrometer or similar. It also specifies a pre-installation heating cycle for the slab, stating:

- To dry the slab adequately, the heating system should be activated, and the water heated to a specific temperature as follows:
    - Day 1: 20 ºC
    - Day 2: 30 ºC
    - Day 3: 40 ºC
    - Day 4: 50 ºC or the maximum planned operating temperature. This should be maintained constantly for a minimum of 7 days.

- To cool down the slab, the flow temperature should be cooled to a specific temperature as follows:
    - Day 12: 40 ºC
    - Day 13: 30 ºC
    - Day 14: 30 ºC
    - Day 15: The underfloor heating should be switched off.

At the Inveresk site, this heating and cooling regime was followed as closely as possible, with the maximum planned operating temperature of 45 ºC. Table 10 lists the dates and temperatures for the processes.

Before the timber was laid, Fairbrother monitored the slab's MC and relative humidity. See Figure 26 above.

The timber overlay

Several factors were considered in determining the strip flooring and other products included in the prototype system. These included:

- Product availability in the volumes required for the projects.
- Ruggedness and wear in the floor over time. The floors are ground-floor area in a public building with 'normal' pedestrian traffic, so robust use is expected and floor recoating is desirable. BS 08201 defines normal pedestrian traffic as intensities less than 2 000 persons per day, as experienced in large village halls, large assembly halls, school and college classrooms; and in hospitals, hotels, canteens, offices, shops, etc.
- Board and system stability on the floor.
- System insulation. The hydronic heating system provider recommends a maximum R-value of 0.15 for any covering on a heated slab. Table 6 shows the calculated R-value for species and systems combinations. As timber's R-value is inversely related to its density, the R-value of other tested species is slightly higher.
- Future industry use of the research results.

Table 6a: Material calculated R-values

Where R value ($m^2 \cdot K/W$) = Thickness (m)/ Conductivity (W/mK)

Material	Conductivity (W/mK)	Thickness (m)	R-Value
Pine ply	0.100[1]		
9 mm		0.009	0.090
12 mm		0.012	0.120
Hardwood ply	0.140[1]		
9mm		0.009	0.064
12mm		0.012	0.086
Bluegum (density *998 kg/m³*)	0.221[2]		
12mm		0.012	0.054
13mm		0.013	0.059
19mm		0.019	0.086

[1] National Construction Code (2019)
[2] Calculated value, Conductivity equation as below (Niemz, 1993)

$$\lambda_{\perp} = 0.026 + 0.195 * \rho_{12\%} * 10^{-3}$$

$\lambda_{\perp}$ = Thermal conductivity perpendicular to the grain [W/me]

$\rho_{12\%}$ = Density at 12% MC [kg/m^3]

Table 6b: Calculated system R-values

Where Total R value = $Rvalue_a + Rvalue_b$

Combinations	$Rvalue_a$	$Rvalue_b$	Total R-Value
Big River Timber's Amourply			0.074*
Pine ply (12mm) + Blue gum (19mm)	0.120	0.086	0.206
Pine ply (9mm) + Blue gum (19mm)	0.090	0.086	0.176
Pine ply (9mm) + Blue gum (12mm)	0.090	0.054	0.144
H/wood ply (12mm) + Blue gum (19mm)	0.086	0.086	0.172
H/wood ply (9mm) + Blue gum (19mm)	0.064	0.086	0.150
H/wood ply (9mm) + Blue gum (12mm)	0.064	0.054	0.118
Blue gum (19 mm) - direct stick	0.086		0.086
Blue gum (13 mm) - direct stick	0.059		0.059

* This is a supplier provided figure

Given these considerations, the preferred system for the installation is 85 x19 mm secret nail profile solid timber boards glued to a 9 mm hardwood ply substrate, directly fixed to the slab over a moisture barrier. This system has a calculated R-value of 0.150.

- A plywood substrate was preferred to direct stick of boards as it provides dimensional stability and a buffer to any thermal shock from the slab.
- A 85 mm wide board limits individual board shrinkage and the size of potential gaps with changing MC conditions.
- A 19 mm board was preferred to a 12 mm board due to its increased stability with changing MC conditions. The thicker board also increased the floor service life and allows for it to be sanded and recoated more times than a thinner board.
- Native forest Tasmanian blue gum was the preferred species due to its density and ruggedness. However, it is the darkest of the timbers tested.
- Three other species were included to generate comparative results and additional options for the projects and for industry.

Table 7 lists the species included in the trial, their resource, supplier and the number of rows of boards installed in each section.

Table 7: Selected species and supplier

Species	Resource	Supplier	Name Tag	Number of rows installed
E. nitens	Plantation	Britton Timbers	N1	12
Blue Gum	Native forest	Neville Smith Forest Products	BG1	11
Blue Gum	Plantation	Britton Timbers	BG2	13
E. obliqua	Native forest	Britton Timbers	O1	12

Timber preparation

AS 2796 Timber—Hardwood—Sawn and milled products establishes MC requirements for milled hardwood flooring of an MC between 9 – 14%. As the expected equilibrium moisture content (EMC) for boards in the floor in service was estimated at 9-10% MC, attempts were made to ensure the timber was close to this MC at the timber of laying.

The boards were secured from the suppliers and stacked in a conditioned room while the slab was built. Table 8 shows the core and case MC of samples (to AS1080.1) in mid-August prior to expected installation.

Table 8: Species MC prior to installation

Species	Resource	Name Tag	Ave MC: case	Ave MC: core
E. nitens	Plantation	N1	10.01%	10.57%
Blue Gum	Native forest	BG1	11.11%	11.75%
Blue Gum	Plantation	BG2	10.36%	10.64%
E. obliqua	Native forest	O1	9.38%	9.88%

Flooring installation

The floor was installed, sanded and finished as detailed in Table 9 and Table 10.

Table 9: Timber overlay material specification

Item	Description
Overlay strip flooring	Boards: 85 x 19 quarter-sawn, end-matched, secret nail strip flooring in nominally 1 m wide panels of plantation Tasmanian Shining gum (*E. nitens*), Tasmanian plantation blue gum, native forest Tasmanian blue gum and Messmate (*E. obliqua*)
Substrate	9 mm Ta Ann hardwood ply underlay.
Moisture barrier	Fairbrother-supplied plastic sheet
Adhesives	Elastomeric floor adhesive: Soudal Parquet SMX-30 or similar
Coating	Loba 2K Supra and Loba 2k Duo 2 pack polyurethane finish to half of each panel over a compatible sealer applied to fill up any joints between the boards.

Table 10: Timber overlay installation arrangement

Item	Description
Install the moisture barrier.	Install a moisture barrier to the floor. Overlap 300 and tape joints
Install the plywood substrate	Install a single layer of plywood across the floor, over the membrane with the grain of the outside veneer parallel to the long direction of the slab. See Figure 27. Fix the plywood sheets through the membrane to the slab with 6.5 mm spikes Install 28 fixings similarly spaced (4 rows of 7 spikes down the length of the sheet) with the outer rows of spikes 75 mm to 100 mm from the sheet edge.
Install the timber flooring	Install and secret nail the flooring to the ply on a full glue bed to the manufacturer's specification. Weight the boards down if required to ensure full contact with the glue. Allow a min 5 mm gap between each section of flooring. The board length is to run across the width of the slab, at rights angles to the ply's top grain. See Figure 30.
Install sample boards	Install one nominal 250 mm long sample board in each flooring type in the centre of each section (prior to coating).
Sand the floor.	Fill and sand the floor flat and level in line with industry practice.
Coat the floor.	Coat the floor with the selected finishes. Coat the sample boards separately. Ensure that they can be removed and reinstalled after coating. See Figure 29.
Install floor enclosure	To reduce draughts and maintain consistent conditions over the floor, install a nominal 1.5 m high enclosure around the floor: Frame wall panels with 90x35 pine, and clad the outside face with building wrap. See Figure 31.
Maintain the internal temperature conditions	Maintain the internal temperature conditions at 20 degrees C and a target RH of 50% after the pre-installation heating cycle and during flooring installation. During installation, room temperatures should not fall below 15°C and the RH should not fall below 40% or exceed 60%.

During the ply substrate's installation, a puncture occurred to the heating line. A section of floor was removed, the puncture repaired, and the substrate reinstalled. See Figure 28.

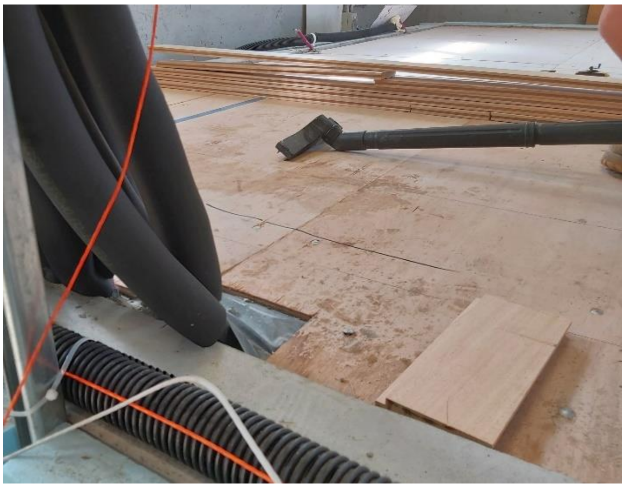

Figure 2: Plywood substrate over plastic moisture barrier

Figure 3: Repair to punctured water pipe

Figure 4: Finishing coat to the sanded flooring panels. Note the two floor finishes

Figure 5: Completed flooring panels

Figure 31: Protective enclosure around the floor

System instrumentation

System instrumentation included temperature sensors in and on the slab and timber floor, a temperature and humidity sensor over the floor and timber sample boards.

To determine the temperature change and heat flow through the system, temperature sensors were positioned through the floor build-up and connected back to a data logger. To ensure assessment confidence, sufficient sensors were installed to allow for adequate results if some failed. The sensors were positioned with:

- Eight sensors in the slab generally adjacent to the hydronic heating lines. Two of these were at the infeed and outfeed lines. See Figure 32.
- Four sensors directly under the plywood, over the plastic. See Figure 33.
- Four sensors directly under the flooring with one under the centre of each panel. See Figure 34.
- One sensor fixed directly on the top of the flooring. See Figure 35.

In addition, a temperature and humidity sensor was positioned nominally 1.2 m over the centre of the floor

Nominal 250 mm long sample boards was established in the centre of each flooring type as it was laid. One side of the groove in the board was removed to ensure it could be easily removed. This initial set of sample boards was replaced in December 3 and subject to MC assessment to AS1080.1. Figure 35 shows the sample boards, the top temperature sensor and the humidity sensor locations.

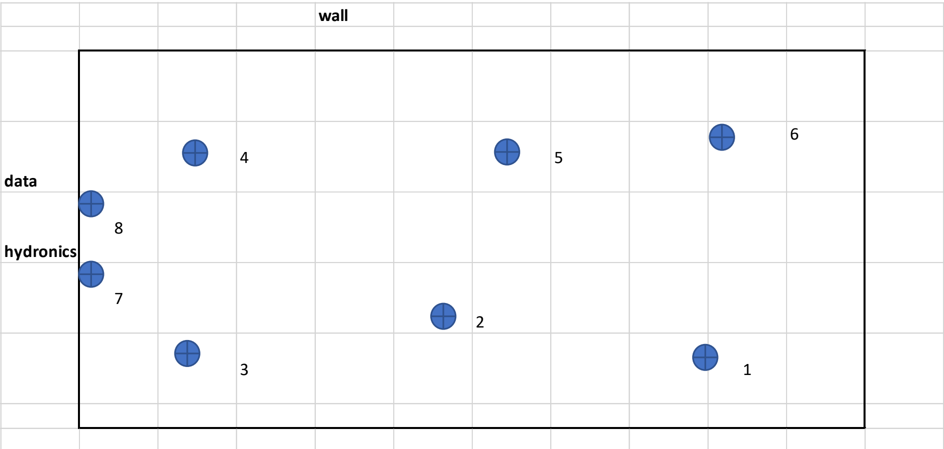

Figure 32: Location of temperature sensors in the slab

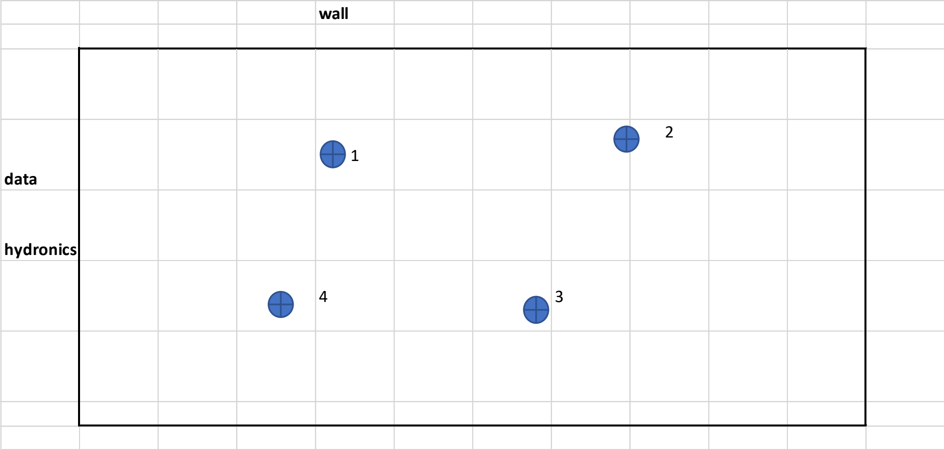

Figure 6: Location of temperature sensors directly under the plywood substrate

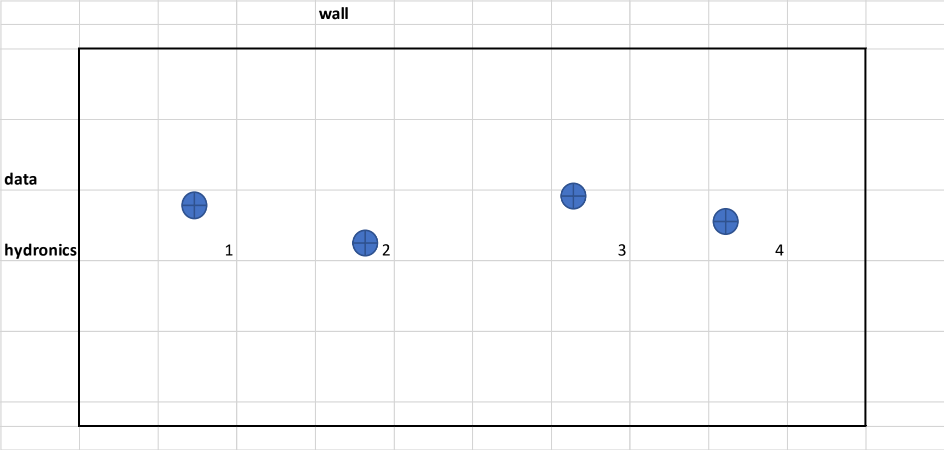

Figure 7: Location of temperature sensors directly under the strip flooring

Figure 8: Location of sample boards, and above floor sensors

Performance monitoring

The system's performance is being monitored as the floor is heated to simulate the building's winter and summer operational conditions. Table 10 lists the planned condition simulations. Originally, only Trials 1, 2 and 3 were planned. However, given the lack of apparent movement in the floor at the end of Trial 2, Trial 2a and Trial 2b were added to the program. The temperatures in this table are the controller's set point temperatures for water in the hydronic system.

The sensors described above monitor temperature through the systems and temperature and humidity above it. In addition, the species panels are monitored to determine:

- Their original condition, such as density to AS 1080.1 and hardness to ASTM D143: Standard test method for small clear specimens of timber.
- Change in MC with sample boards and a resistance moisture meter.
- Board movement in the sample board and across the floors.

Table 11 lists the general monitoring sampling rate.

Table 1: Heating and cooling cycle trial

Trial	Description	Duration	Heating profile
Trial 1	Timber acclimatisation / curing.	7 days	After floor coating, maintain the controller temperature at 20 ºC for one week.
Trial 2	Winter condition simulation	42 days	Two weeks with the controller temperature at 23 ºC, then two weeks at 25 ºC, and two weeks at 27 ºC.
Trial 2a	Extended winter simulation	40 days	Two weeks with the controller temperature at 30 ºC, 5 days at 35 ºC, and three weeks at 39 ºC.
Trial 2b	Cycled simulation	20 days	Ten days at 20 ºC, then ten days at 35 ºC.
Trial 3	Summer condition simulation	28 days	One week with the controller temperature at 23 ºC then heating sufficient to maintain the timber surface at 20 ºC.

Table 2: Sampling rate

Sampling rate	Type of measurement
10 min	Temperature: all sensors Relative humidity: above centre of the floor.
Three times a week.	Sample board MC. Resistance MC of points. Cover width and thickness of sample boards. Floor observation: any cupping or gapping over the whole floor.

Moisture content

To assess moisture content, the sample board is weighted on each occasion and the MC calculated. Board MC is also measured with a resistance moisture meter calibrated for Douglas Fir before temperature and species corrections are applied. One reading is taken in a fresh location each time along two lines. Line A is 650mm from east edge and Line B is 600mm from west edge of timber panels.

Board movement

The width and depth of each sample boards are measured using vernier callipers. Any gaps, cupping, peaking, coating behaviour and any other effects are observed, monitored and photographed.

Figure 9: Floors during the heating trial

Results

This report covers construction of the prototype and its monitoring as the floor was heated from October 8 till December 17, 2021, with additional observations on floor performance to January 11, 2022. This is to the middle of Trail 2a shown in Table 10. Table 12 provides and activity timeline.

Table 3: Activity timeline

Date	Action	Manifold temperature
13 July 2021	Slab topping installed and curing.	20 ºC
23 July 2021	Slab conditioning: Base temperature	20 ºC
26 July 2021	Slab conditioning: Temperature increase	30 ºC
28 July 2021	Slab conditioning: Temperature increase	40 ºC
30 July 2021	Slab conditioning: Temperature increase	45 ºC
9 August 2021	Slab conditioning: Temperature hold	45 ºC
10 August 2021	Slab conditioning: Temperature decreased	35 ºC
11 August 2021	Slab conditioning: Temperature decreased	30 ºC
12 August 2021	Slab conditioning: Temperature decreased	25 ºC
13 August 2021	Slab conditioning: Temperature decreased	OFF
19 August 2021	5 days after shut down	OFF
16 September 2021	Ply installation commenced and hydronics punctured	OFF
26 September 2021	Hydronics repaired and ply installation completed.	OFF
28 September 2021	Hydronics on	20 ºC
29 September 2021	Floorboards installed	20 ºC
30 September 2021	Floorboards coated and curing	20 ºC
8 October 2021	System temperature increase	23 ºC
22 October 2021	System temperature increase	25 ºC

15 November 2021	System temperature increase	27 ºC
17 November 2021	Protective enclosure around the floor installed	-
29 November 2021	System temperature increase	30 ºC
3 December 2021	Sample set replaced	-
13 December 2021	System temperature increase	35 ºC
17 December 2021	System temperature increase	39 ºC
12 January 2022	System temperature decreased	20 ºC

Slab MC

Fairbrother measured the slab's relative humidity after the conditioning period. However, it did not vary from 99%. Given this, the moisture barrier and ply layer were installed.

Heated subfloor

Figure 37 shows the temperature from the slab sensors. Figure 38 shows the temperatures under the ply (on the top of the slab) in the upper chart, and the temperatures under the floorboards in the lower chart. Figure 39 shows the variation in average temperature between:

- the manifold input (2 sensors - hydronics infeed and outfeed)
- The top of the slab (4 and then three sensors under the plan)
- The underside of the solid timber (4 sensors).

Several sensors provided highly variable results and were excluded from later calculations.

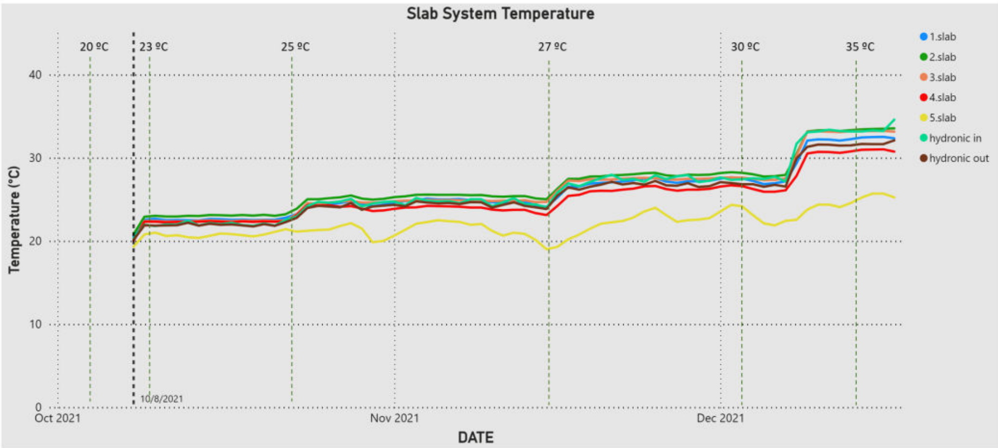

Figure 10: Slab temperature over time

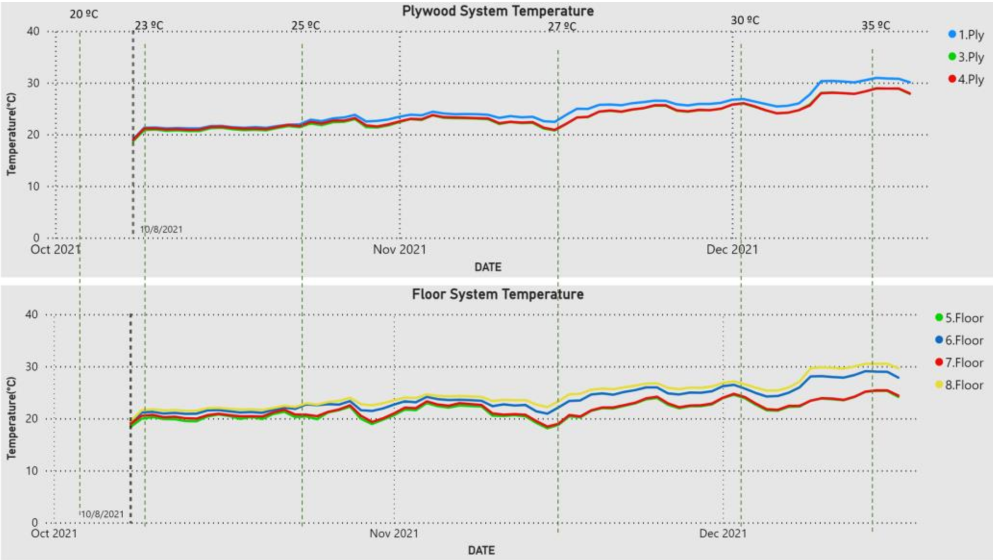

Figure 11: Temperature under the ply and under the flooring over time

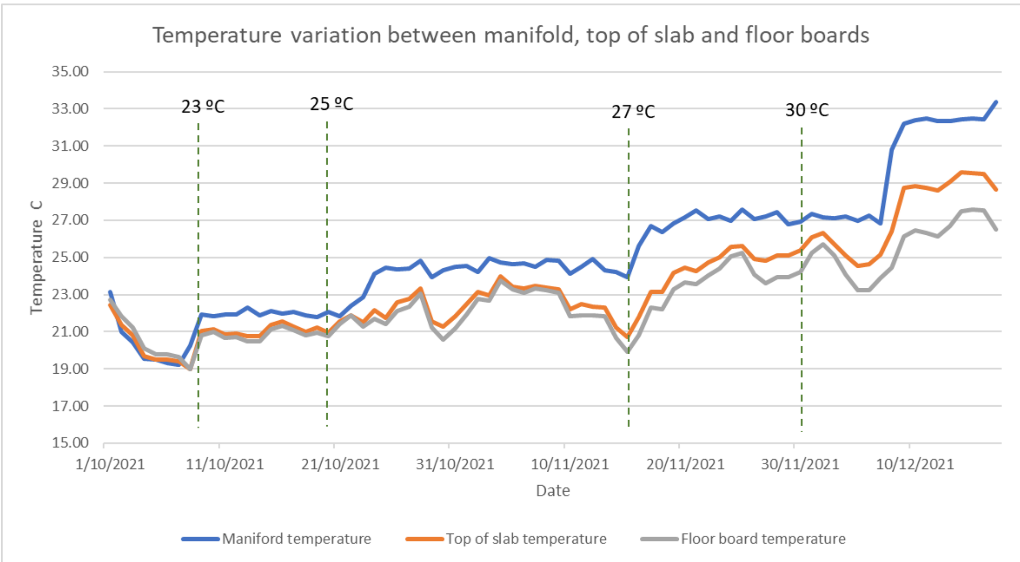

Figure 12: Temperature variation between the manifold, top of slab and under the floorboards over time

Timber characteristics and performance

Density and hardness

Table 13 lists the density and hardness of the four species in the panels, with Native forest Blue gum being the densest material, followed by plantation Blue gum.

Table 4: Species density and hardness

Species	Resource	Name Tag	Density (Average kg/m^3)	Hardness (Janka)
E. nitens (Shining gum)	Plantation	N1	541	*3.7*
Blue Gum	Native forest	BG1	998	8.0
Blue Gum	Plantation	BG2	635	4
E. obliqua (Messmate)	Native forest	O1	618	4.4

Moisture content over time

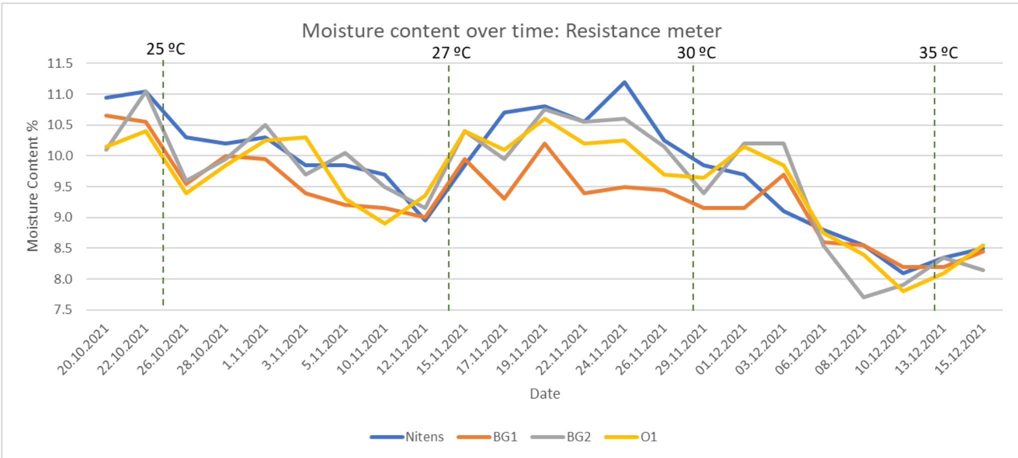

Figure 40: Moisture content variation assessed by resistance moisture meter

Figure 41 shows a general decline in board MC assessed by resistance moisture meter after species and temperature correction. The variability in the results is indicative of the range found with resistance meter readings across different boards

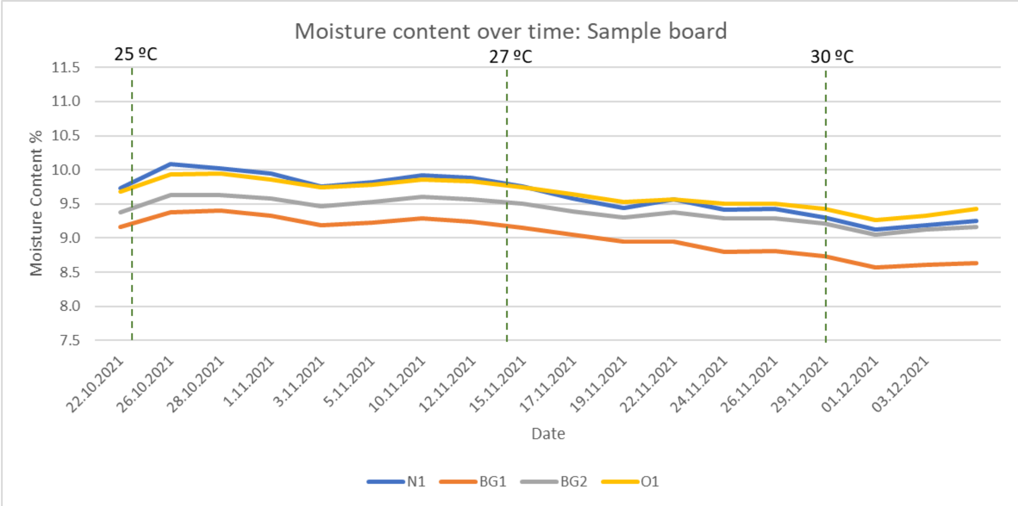

Figure 13: Moisture content variation assessed by sample board – 22/10/21 – 3/12/21

Figure 42 shows the change in board MC assessed by sample boards and oven dry moisture assessment to AS1080.1 from 22 October to 3 December 2021. This indicates that the timber was at an average MC of 9.5% when first assessed and reduced gradually to an average of 9.1%. Figure 42 shows the change in board MC assessed by the replacement sample boards 6 December 2021 to 11 January 2022. This indicates that timber was at an average MC of 10% when first installed and reduced gradually to an average MC of 9.3%.

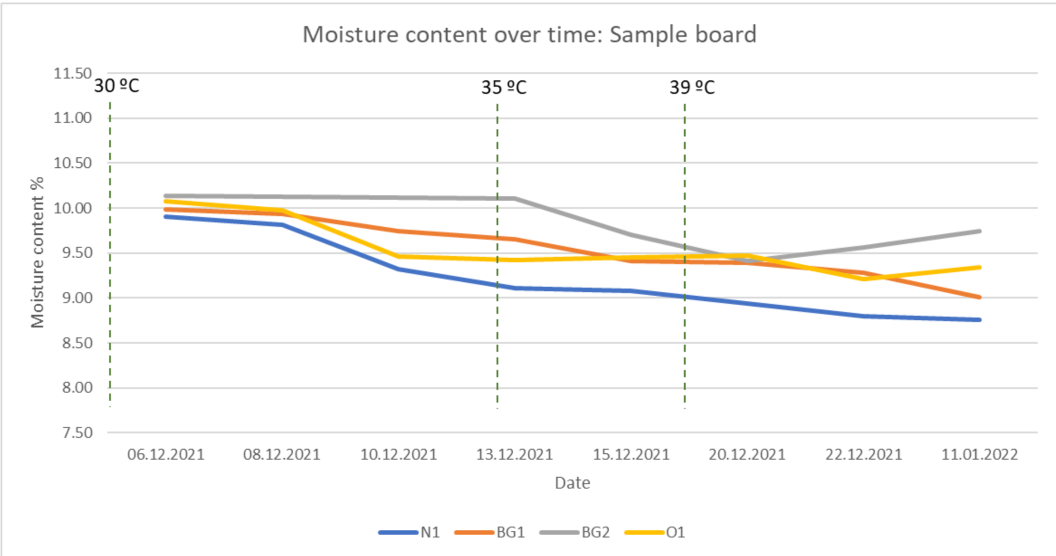

Figure 42: Moisture content variation assessed by sample board – 6/12/21 – 11/01/22

Board movement over time

Little or no movement was detected in floor surface during 2021. However, slight shrinkage was detected at several locations for all species on 11 January, after the hydronics control was set to 39 ^{O}C and the surrounding room was closed for the Christmas lockup.

Figure 43 shows measured board movement of the initial sample boards till 3 December. In effect, the boards show no size reduction. Expected movement of an 85 mm quarter sawn board with a MC change of 1 % is 0.2 mm.

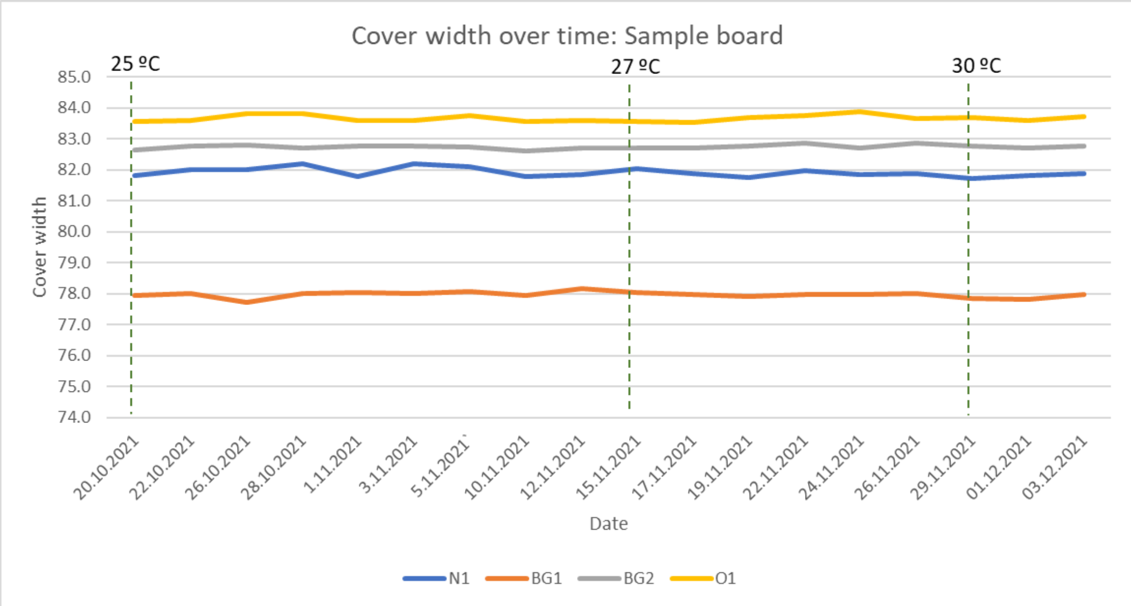

Figure 14: Change in sample board cover width – 22/10/21 – 3/12/21

Discussion

This sub-project's objectives are:

- To determine if the prototype system is fit-for-purpose for proposed University of Tasmania (UTAS) and similar commercial building projects.
- To determine and compare the performance of the four Tasmanian hardwood species as part of a strip flooring system installed over a heated slab.

The results above indicate that, if installed at the specified MC, the system's stability appears to be fit-for-purpose for all species during the floor's winter heating cycle.

During the test period till December 17, 2021, the top of the slab temperatures rose by 10.6 °C from 19 °C to 29.6 °C while the underside of the timber temperatures rose by 8.6 °C from 19 °C to 27.6 °C. During the period to December 3, the timber's MC reduced gradually from an average 9.5 % to an average 9.1 %. Notwithstanding these changes, the system performed satisfactorily. Very few discernible gaps developed and there was no apparent loss in board stability or flatness.

Additions monitoring and data assessment

Additional monitoring and data assessment is required to confirm the system's performance across seasons, particularly from winter into summer, or in the variable conditions of spring. This includes

- Temperature cycling between winter and summer conditions.
- Overall thermal, MC and stability performance.
- The thermal lag between hydronic input and temperature output through the floor. This may impact the design of the hydronic system.
- The impact of direct sunlight on the floor to the overall timber hydronic flooring system.