ACIAR PROJECT FST/2019/128

Suitability and Market Potential of Coconut Wood EWP

Coconut and other non-traditional forest resources for the manufacture of Engineered Wood Products (EWP)

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Activity 4.2

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Coconut EWP Suitability and Market Potential

Executive Summary

The aim of this review was to report on suitable wood products where the coconut wood resource could be used in conjunction with or by substitution for other material types in Fiji. This project was conducted in collaboration with Mr. Divnesh Swamy, Fiji National University (FNU). Through a desktop investigation into types of engineered wood products (EWPs), a total of 22 different veneer-based product groups were identified globally, further defined as “plywood”, “LVL”, and “composite” groups. From these groups and a detailed literature review of coconut wood and cocoveneer properties, the number of suitable groups was focused to 14. These were considered as either ‘likely’ or ‘highly likely’ in terms of the coconut wood or cocoveneer material properties suitability to meet the products’ key market performance criteria. These products were primarily non-structural and in visual applications.

The findings of the desktop review were refined through an industry consultation in Fiji. Members of the Australian Centre for International Agricultural Research (ACIAR) team visited companies across 4 major cities and towns in Fiji (Suva, Nadi, Labasa, and Savusavu) to question their perception of coconut wood products (cocowood, cocoveneer and cocoveneer EWPs) and how they could be incorporated within their businesses. The consultation suggested the majority of wood products currently used in Fiji were veneer-based EWPs suggesting the cocoveneer EWPs would have greater success compared to cocowood products. This finding reduced the number of product groups of interest to 7. Interviewee’s highlighted that 95% of these veneer-based EWPs fell within the non-structural and visual application grouping. The suggested products considered suitable for cocoveneer EWPs was shortened to 3 as flooring overlay (22%), cabinetry/ joinery (17%), and window/ door frames (15%).

Challenges in cocoveneer EWPs accessing the current local market were considered as the primary area for hesitation. Some of the main challenges were the unknown cost of production (21%), durability and treatability of cocoveneer EWPs (18%), and appearance/ workability of potential products (14%). It is recommended that future research and development activities focus on these areas of concern highlighted by interviewees to build confidence in the product for both industry and the market (consumers).

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Abbreviations and definitions

Coconut wood (Coconut palm logs): Coconut wood (material from the coconut palm - *Cocos nucifera*) a member of the monocotyledon plant family (along with other palms, bamboos and grasses) and therefore not considered a typical 'timber' species. The palm fibre has a large variation in density, from outer to centre with the fibre at the outer perimeter has properties similar to those of hardwood [1, 2].

Cocowood (Coconut sawn wood): Defines the processing technique of sawing the coconut wood into dimensional lumber or sawn boards.

Cocoveneer (Rotary peeled coconut): Defines the processing technique of rotary veneer peeling coconut logs to produce veneers sheets for engineered wood product (EWP) production.

Cocofibre (particle based coconut palm products): Defines the processing technique of producing wood particles and fibres to be used in particle-based wood product development.

Cocoveneer EWP (Cocoveneer engineered wood product): Defined as a cocoveneer product developed according to either plywood or laminated veneer lumber (LVL) design strategies. The majority of EWPs consist of timber in combination with adhesives. This report has been limited to the review of those adhesive-based EWPs [3, 4].

Plywood: Plywood is made up of veneers bonded together through the use of adhesive, pressure, and heat (depending on the adhesive type) to produce panelised products. Plywood consists of veneers layered perpendicularly to the proceeding layer [5]. The cross direction of the veneers gives plywood mechanical properties in both axial directions as well as dimensional stability from changes due to moisture.

LVL (Laminated veneer lumber): LVL is comprised of wood veneers bonded together through the use of adhesive, pressure, and heat (depending on the adhesive type) to produce a panelised product. These panelised materials are then commonly sawn into structural members in replacement of sawn boards [5]. While similar to plywood, it differs by having the veneers layered with the grain direction running parallel to the major axial direction.

Particle-based products: Particles and fibre-based EWPs is commonly manufactured using the by-product residual waste generated from other processing stages (such as defined above). These particles can range from 2.5 mm to 150 mm, depending on the product (Particleboard, medium-density fibreboard (MDF), Oriented strand board (OSB)) and are mixed with adhesive and pressed to manufacture a panelised product [5-7].

Hybrid EWPs: A hybrid EWP is a product that uses a combination of EWP types or combines them with sawn timber to produce a final product. Hybrid products present a manufacturing method where the most appropriate product type is selected for the intended application [8]. These products can include but are not limited to multi-laminate wood (MLW), blockboard, I-joists (commonly with LVL used as the flanges and plywood or OSB used in the web), and composite panels.

Stress grading: Stress grading (also referred to as mechanical grading) is the process of applying a pre-determined load to a timber product in order to measure the stiffness properties [3].

1 Introduction

The activities described in this report have been conducted by the Forest Product Innovations (FPI) team at the Salisbury Research Facility (SRF) in collaboration with Mr. Divnesh Swamy, Fiji~~an~~ National University (FNU). This report has been conducted as part of the Australian Centre for International Agricultural Research (ACIAR) funded project (FST/2019/128) "*Coconut and other non-traditional forest resources for the manufacture of engineered wood products (EWPs)*", in collaboration with the Pacific Community (SPC), the Fijian Ministry of Forestry, and FNU. A great deal of information has been generated from previous Fiji-focused ACIAR projects (*FST/2004/054 Improving value and marketability of coconut wood* and *FST/2009/062 Development of advanced veneer and other product from coconut wood to enhance livelihoods in South Pacific communities*) on the background to, processing of, and opportunities for coconut wood (referred to through this report as "*cocowood*") in a variety of applications with many technical reports identifying a range of coconut palm-based EWPs.

The focus of this study has been to evaluate global EWP types consisting of sawn, veneer, and particle-based feedstock for utilisation opportunities for the coconut wood resource. Product types where coconut wood are considered a suitable material for use are reported and discussed through this report. This report reviewed published work, expert opinion, as well as key stakeholder consultation in the form of a questionnaire delivered to the Fijian timber and EWP industry. The aim of this study has been to provide information to both the FST/2019/128 project team and Fijian industry regarding potential product ranges for further investigation, development, and marketing. A total of 25 Fijian companies in the timber processing, furniture and joinery, and construction sectors were selected for consultation through this review. The interviewed parties represent the key parts of the timber sector in Fiji, where the companies selected were chosen for their role in the supply chain for timber products. These included EWP manufacturers, construction firms, import and exporters, wholesale and retail distributors, and joinery/ cabinetry businesses.

1.1 Aims and Objectives

This report has been initiated based on the outputs of previous coconut wood utilisation projects funded by ACIAR (*FST/2004/054* and *FST/2009/062*) and focuses on identifying market suitable products for which the material and mechanical properties of coconut wood are believed to align. The objectives of this study have been to conduct a comprehensive review of:

- Globally available adhesive-based EWPs, their intrinsic properties, manufacturing specifications, and product design ranges.
- Potential use of coconut wood for the listed EWPs (as either cocowood or cocoveneer EWPs), and limitations which may constrict its use.
- Market interest and potential demand in Fiji specific for the product range(s) identified.

1.2 Methodology

The methodology for the study was developed to address the following key components:

- A review of commercially and globally available adhesive-based EWPs (specifically their groups as well as required characteristics).
- Investigate and detail the material properties of coconut wood based on relevant published research.
- Identification of coconut wood suited EWPs including target markets, and industry competition (SWOT analysis).
- State of knowledge of coconut wood as an EWP material feedstock in the Fijian timber industry.

A multi-stage method was adopted that started with a desktop review of globally available EWPs and their range of design and application characteristics. Products intended for structural, non-structural, interior and exterior applications were reviewed to ensure wide-ranging possibilities were considered for coconut wood. The next phase was to evaluate the identified product types and their market driven specifications against the material properties and other known performance characteristics of coconut wood (e.g. mechanical properties, durability, visual aspects, etc.). Several suitable product groups were then identified where coconut wood could replace current timber species/ material types in the Asia-Pacific region. A final stage focused on engagement with 25 Fijian industry collaborators representing the majority of wood processing, manufacturing and building sectors in Fiji to understand the timber products currently produced and used in the region.

2 Background – Coconut wood processing

Coconut wood is a dense material that is likened to other tropical hardwoods like teak or mahogany. One of the advantages of coconut wood is that it is a by-product of coconut farming, meaning that it is sourced from coconut palms that have reached the end of their commercial fruit-bearing life. Through the sale of coconut palms for cocowood processing (sawing), farmers can generate additional income to offset the cost of senile palm removal and replanting. Furthermore, the use of coconut wood products can also help to reduce the demand for other types of tropical hardwoods which are becoming less available. With an estimated 65,000 hectare (Ha) of current coconut plantations across Fiji islands (where close to 60% of that stock is considered senile), the potential resource for coconut wood is considered plentiful and serves a direct incentive to growers to re-plant when the tree becomes 'senile' [9, 10].

Although coconut wood has many potential timber applications, there is only one producer of coconut wood products in Fiji, Pacific Green Industries. The company producers high-end, decorative furniture products sold both nationally and internationally. Some reasons for the limited commercial adoption of coconut wood products in Fiji is due to difficulties in processing and working with the material [11]. While there are numerous local community level uses for coconut wood (e.g. firewood, non-critical infrastructure, tourist artefacts, etc.) pursuing higher value added alternatives such as EWPs presents more attractive opportunities for local and regional economies. Sawing senile coconut palms into cocowood is mainly hindered due to the enhanced spiral grain inherent to the resource, resulting in board twist in the majority of trials [12-14]. This distortion is further exacerbated by the density variation with some palms recording a density variation of > 700kg/m^3 at the outer ring to < 300 kg/m^3 at the core [15]. This density variation results in a wide range of mechanical properties depending on the board or veneers position from within the palm. Table 1 presents the results reported by Bailleres, et al. [11] which details the tested mechanical property ranges for sawn coconut wood (cocowood) boards. Bailleres, et al. [11] found the processing of cocowood can be conducted using conventional sawmilling equipment although, requires high-speed blades be fitted with either tungsten-carbie or stellite-tipped saw blades. The resulting relatively low recovery of sawn boards also challenges financial viability.

Table 1: Cocowood mechanical properties on sawn boards. [15].

MECHANICAL PROPERTY	RANGE (LOW TO HIGH)
DENSITY (BASIC)	100 – 1,020 (kg/m^3)
MODULUS OF ELASTICITY (MOE)	2 – 25 (GPa)
MODULUS OF RUPTURE (MOR)	28 – 108 (MPa)
JANKA HARDNESS	0.7 – 23.9 (kN)

These results impose limits on the applications for cocowood products such as flooring and structural beams. For example, it is common practice to limit flooring materials to Janka hardness rated timbers $\geq$ 5.5 kN meaning a proportion of the timber recovered from log processing would not be suitable for flooring [16]. From these results, it can be suggested that the application of the final product is highly defined by the material properties, or conversely, the products is designed to meet a certain product application. Through the sawing studies conducted in Arancon [12], Gibe [13], and Killmann and Fink [14], a series of selection criteria were defined for cocowood boards based on the visual assessment of vascular bundle patterns and density which appeared to be related, as well as colour and homogeneity in grain patterns [17]. These grading techniques were also applicable to rotary peeled coconut wood (cocoveneer – Section 2.1). Peeling often provides an effective means of improving volume recovery versus sawing [18]. Limitations in producing cocoveneer found thresholds in minimum thicknesses that can be peeled from each density group. Due to the wide variation in density as well as the large anatomical structure, a minimum working veneer thickness of 2.5 mm was determined [18, 19]. Peeling thinner than this produces large amounts of checking in the veneers making them difficult to work with and affecting mechanical performance [18, 19]. While it is possible to increase the thickness of veneers, this should be targeted at lower density sections of the palm as peeling thicker on high density sections will put un-necessary load on the peeler blade [18, 19]. In practice it is uncommon to peel multiple thicknesses from a single log billet and is thus suggested veneering focus on a single thickness of around 3.0 to 4.0 mm.

Previous studies separated cocoveneer into four groups of low, medium, medium-high and high density [20]. Of the processed palms, 35% of the veneers fell within the medium-high (601 – 749 kg/m^3) group, followed by the medium group (451 – 600 kg/m^3) with 32%, low ($\leq$ 450 kg/m^3) with 22%, and high ($\geq$ 750 kg/m^3) with 11% [20]. From this, the medium-high and medium groups made up 67% of the generated material after peeling with only 11% falling into the high category. This suggests that applications requiring high density materials (often necessary for structural applications) may not be as lucrative as alternatives (low or no structural requirement). Trials investigating potential EWP types using cocoveneer used a blend of veneer densities to produce a series of plywood and LVL products [20]. The products were evaluated for their bond quality and mechanical performance (modulus of elasticity - MOE, modulus of rupture - MOR, and panel shear) according to the relevant Australian standards (AS/NZS 2269.1 [21] and AS/NZS 4357.2 [22]). The results ranged from F4 (6,100 MPa) to F22 (16,000 MPa) for the plywood panels depending on the layup of veneer density ranges [20]. The LVL produced similar ranges depending on the veneer density composition. Irrespective of the layup or product type (Plywood or LVL), a type A bond quality was achieved in the trials when materials were manufactured using a phenol formaldehyde (PF) type adhesive [20]. One of the main limiting properties for cocoveneer plywood was panel shear, resulting in 1 to 2 stress grades lower than the MOE and MOR values. It is hypothesised that this is due to the large vascular bundles throughout the material, weakening the shear capacity.

2.1 Grading characteristics for cocowood and cocoveneer

A comparison from Gonzalez [1] and Butterfield, et al. [2] looked at the differences between the characteristics of traditional timber species against those of monocotyledon plants. Monocotyledons such as coconut palms have no annual rings, heartwood, ray cells, branches or knots and the bark or cortex of the palm is not demarcated (hard to remove). Due to these anatomical differences between coconut palms and traditional timber species, the conventional sawn and veneer grading standards do not apply [19]. Rather, the grading of coconut wood has been driven by the application of the product [19]. Based on the information presented in Section **Error! Reference source not found.**, a series of grade characteristics have been devised.

2.1.1 Density:

The structure of the senile coconut palm can be separated into 3 to 4 density groupings (Figure 1) as well as an outer 10 to 15 mm thick layer referred to as the cortex [19]. The cortex has been likened to bark as it is a protective fibrous tissue layer around the outside of the palm [19]. The density groups presented in Mcgavin, et al. [20] shows the expected ranges commonly achievable in senile coconut palms. Conventional sized sawn cocowood boards provide significant limitations on separating by density due to this large density variation. This density variation also leads to drying stress and board distortion.

Figure 1: Cross-section of coconut palm showing vascular bundling (density distribution) from centre to the outer cortex. Adopted from *McGavin et al*. [19].

2.1.2 Surface roughness and flatness:

In traditional wood species, roughness is commonly associated with interlocked grain, spiral grain or other grain deviations, especially associated with knots. However, due to the anatomical nature of coconut wood, the bundling of vascular fibrous tissues can result in varying degrees of surface finish or roughness specifically for cocoveneer material [11]. The surface roughness can drive both the processing settings and limitations as well as guide the product application. Peeling trials conducted by McGavin [23, 24] scored veneer surface roughness between 1 to 8 where 1 was considered “smooth” and 8 “very rough”. The trials both found a roughness score of 3 dominated the available resource indicating that the veneers would likely require sanding to produce a “smooth” (score of 1) finish. Factors that can be manipulated to improve surface roughness include peeling thickness, feed rate (speed), and log pre-conditioning [23, 24].

2.1.3 Splits and brittleness:

Drying schedules and the relief of internal stresses contributes to the presence of end or surface splitting across sawn boards and veneers [25]. In sawn material, the presence of splits are commonly due to either felling impact response or drying stress relief, although coconut wood is not susceptible to felling splits [26]. While the presence of splitting in sawn material can be controlled to a degree through improved drying schedules, splitting in veneers is more concerned with the processing settings. Peeling studies conducted on cocoveneer by McGavin [23] found veneer compression, shrinkage and other stress releases to be the main causes of splitting. In both studies by McGavin [23, 24] splitting of cocoveneer was assessed using a scoring system between 1 and 10 where 1 indicates "no splits" and 10 indicated "many splits". In the earlier trial conducted by McGavin [23] the distribution of cocoveneer split quality resulted in the majority returning a 1, 2, and 5 where log pre-conditioning and lathe settings were thought to be the cause. Later trials by McGavin [24] were able to overcome the poor quality from previous trials through the pre-conditioning of logs and lathe optimisation to return a split score of 1 for over 60% of the veneers.

The brittleness of the material relates to its tendency to split which was monitored in the peeling trials [23, 24]. Brittleness, like splits is in part due to the material properties and with coconut wood is hindered through the fibre bundles in the higher density material. McGavin [23] noted brittleness as an area requiring improvement in peeling which was targeted through improved processing techniques that were implemented in later trials, with increasing veneer thickness >3.0 mm and improving drying methods proving beneficial [24]. The difference between the two trials was emphasised when comparing split data where trial 3 [23] resulted in approximately 50% of the assessed veneers produced a score of 1 to 3. Trial 4 which consisted of improved drying schedules resulted in over 60% of the assessed veneers producing a score of 1.

2.1.4 Colour:

A key feature of coconut wood that presents a point of difference compared with traditional wood species on the market is its visual appearance. Both cocowood and cocoveneer produces a spectrum of colourful surface finishes due to the parenchyma tissue with dark strokes (fibres) scattered throughout. The consistency and number of fibres corresponds to the increase in material density which correlates to a deepening in colour. Due to their large surface area, the impact of the colour differences can be seen clearer on cocoveneer material. A selection of low to high density cocoveneer material is presented in Figure 2 [27].

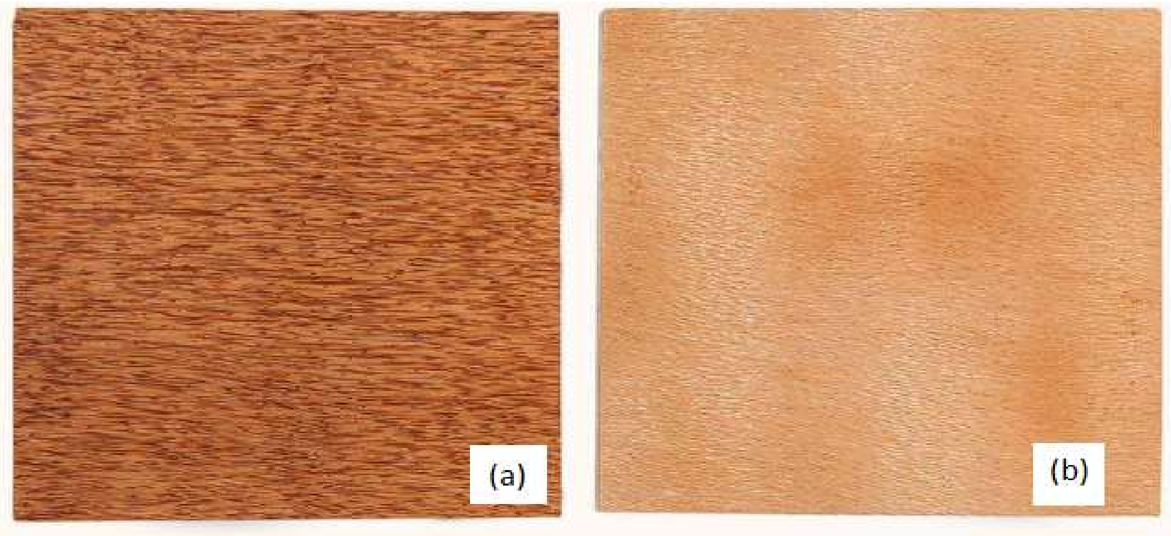

Figure 2: Cocoveneer colours where (a) represents high density, (b) medium-high density. Adopted from McGavin et al [27].

3 Veneer-Based EWP Types and Applications

Veneer-based engineered wood products (EWPs) can optimise the amount of resource recovered as well as ensure the material generated is consistent in quality with low variability regarding material characteristics (density, colour variation, heartwood to sapwood content, etc.) [28]. The following sections detail the various product groupings within the plywood (Section 3.1) and LVL (Section 3.2) groups, their application(s), design specific information, and suitability of cocoveneer.

3.1 Plywood

While plywood has been described earlier, it is important to consider the various classifications or product groups that exist within the plywood category. Plywood has a range of applications that are used globally which are governed by the material characteristics, and adhesive type. Through the scope of compositions available, plywood can be used for applications in exterior or interior uses, as a structural or non-structural product, and scenarios where it is either visible or covered. With these applications comes a range of assessment criteria such as:

- Veneer quality
- Adhesive type
- Durability
- Mechanical performance
- Density
- Surface finish
- Coating
- Preservative treatment

Plywood is required to meet a series of performance-based assessments irrespective of being structural or non-structural, interior or exterior products. While this section discusses the various plywood groupings, the performance and application criteria used is also introduced.

3.1.1.1 Mechanical properties:

Mechanical testing is used to understand the performance criteria and limitations of the product which can be implemented during the design phase [29]. Mechanical testing requirements vary based on the application of each specific product. For example, Janka hardness testing is not required for products that are not intended for flooring. The MOE is a commonly referred to property in product grading and stress grade assignment, it has therefore been highlighted, where relevant, through the product description sections of this report.

3.1.1.2 Bond quality:

Adhesive makes up a significant proportion of the product ingredients (veneers and adhesive) for adhesive-based EWPs and thus the integrity or strength of the bonded interface needs to be quantified in order to confirm the quality. Depending on the application of the product, the intensity of the testing is altered [30].

3.1.1.3 Formaldehyde emissions:

As formaldehyde is considered a carcinogenic chemical, the level of emissions emitted from a sample using a formaldehyde-based adhesive is required to be monitored. While the standards for evaluating the emission amount vary across the globe, the allowable emission levels are relatively consistent [29, 31].

3.1.1.4 Coatings and overlays:

Depending on the application, market requirements may call for either a specific coating or overlay to be used in some product groups. Examples of these would be to enhance the workability or floor panels with non-slip coverings or an overlay sheet for manufacturing formply.

3.1.2 Bracing ply

Bracing plywood, as the name suggests is used in structural applications requiring bracing of a framed structure, commonly in housing. Bracing ply is regularly used as sheathing on house frames to provide additional strength and resistance to horizontal racking forces induced by high wind loads. The bracing ply also provides a barrier to reduce air and moisture ingress into the structure [32]. Due to its application being across stud framing, the ply sheets need to be relatively thin to avoid bowing in the sheets that span between studs and to avoid interference with cladding systems. Because of this, bracing ply commonly ranges from 4 to 7 mm in overall thickness and individual veneer thicknesses of 0.9 to 2.3 mm. As a structural product, bracing ply is required to meet both structural and bond integrity testing where the plywood must meet a Type A bond classification (durable service class 3 product) as well as a stress grade rating obtained from mechanical testing. The modulus of elasticity (MOE) for bracing ply ranged from 9,100 to 18,500 MPa globally. While density is not a specified characteristic of bracing ply, the global range of products researched was found to be 550 to 750 kg/m^3. Bracing ply is rarely a visually exposed product and is in most cases purely for structural purposes, therefore it does not have a visual requirement. That is, as long as the veneer performance is not compromised, superficial defects are acceptable (KEY CRITERIA: Thickness and mechanical properties).

3.1.3 Flooring ply

Plywood when used for flooring can relate to a number of different applications, which have various technical, performance, and visual requirements [33]. Flooring ply can be separated into three main groups as defined by their general applications. The information presented in Table 2 details these groups as well as the technical, performance and visual requirements for the intended applications. Some general properties that span across all of the floor types includes hardness, which is generally identified as an air-dry density upwards of 650 kg/m^3, and coatings for exposed ply panels for workability protection (phenolic film/ fibre-reinforced plastic overlay) or slip-resistance (textured paint/ crushed glass coating).

Table 2: Flooring group specifications for the various applications.

FLOORING PLY TYPE	DESCRIPTION OF REQUIREMENTS
UNDERLAY OR STRUCTURAL SUSPENDED FLOORING	Structural ply floor panels are commonly used to span across floor joints to create multi-level lightweight constructions. This application is a common construction technique used in residential, commercial and office applications. Being a supporting element, the application is governed by a stress grade by which the plywood is graded to; common grades available for this product range from 9,100 to 18,500 MPa regarding MOE with thicknesses ranging from 6.5 to 32 mm. As a structural product used as one of the primary layers in a floor cassette, it is not uncommon for these panels to be covered (acting as an underlay); suggesting visual appeal is not of priority for these ply panels. A critical design criterion for structural plywood is in the bond type which is specified to be a high performing Type A bond. (<u>KEY CRITERIA</u>: Mechanical properties, density, and flatness).
FLOORING PANELS IN BUSES, TRAILERS AND CONTAINERS	As the flooring substrate in buses, trailers, and containers, there are a number of requirements the ply panel must meet in order to be suitable for the application. These panels serve as a protective layer from road noise/ and base structure as well as a workable surface for loading and unloading. These panels are also commonly countersunk into the body or base of the vehicle/ container meaning a minimum and maximum thickness is required. This minimum is commonly reported as a range from

	12 to 28 mm thick. Applications with high traffic movement may call for an abrasion proof coating and a higher density wood type (such as the container ply). (KEY CRITERIA: Thickness, density, flatness and workability).
OVERLAY FLOORING (PLYWOOD, MDF, OR OTHER)	The tongue and groove (T&G) flooring design with solid timber top provides an effective means for thin non-structural sawn sections (the topping) to be used in a decorative way which requires an emphasis on the visual appearance. Veneers provide an optimal solution where clear, high quality face veneers can be overlaid on a lower quality plywood panel or another type of substrate (solid timber, MDF, etc.). While thickness is not generally a critical design parameter for overlay/ T&G or parquetry flooring, common wood-based overlay products range from 7 to 25 mm. Some examples of overlay flooring are shown in Figure 3. (KEY CRITERIA: Visual appearance/ grade/ colour, density, roughness, and flatness).

Figure 3: Flooring examples (overlay & underlay) [34].

3.1.4 Formwork plywood panels (formply)

Formwork plywood panels (commonly referred to as 'formply') is a structural plywood panel that has been overlayed with a smooth phenolic resin-impregnated film bonded to the veneer surface [33]. The formply product was developed for concrete formwork where the resin film protects the surface allowing the product to be re-used multiple times. Common thicknesses of formply can range from 5 to 26 mm in overall panel thickness and individual veneer thicknesses can range from 1.0 to 3.7 mm depending on the target construction strategy (AS6669 [35]). Due to its applications being those of both interior and exterior conditions and the possibilities of concentrated loads being applied across the panel surface, the use of certain formply products is driven by its design and specifications; meaning formply can be used as either a structural or non-structural product depending on the bond quality and stress grade application [33].

While density is not an often-specified characteristic, the range used globally appears to be 550 – 750 kg/m^3. The surface finish or roughness of the plywood panel itself needs to be relatively smooth as this can significantly impact the surface quality of the off-form concrete. It can also impact the bond quality of the resin-impregnated film. Bond quality can range from a Type A, B or C where the bond type required will be governed by the application environment (indoors, outdoors, exposed to environmental conditions). Based on the off form finish class required for the concrete, the formply of the corresponding finish design should be used. According to AS6669 [35], there are four classes of formply surface finishes which correlate to face veneer characteristics such as the thickness and veneer quality. (KEY CRITERIA: Low roughness, flatness, and density).

3.1.5 Acoustic ply

Acoustic plywood panels are either designed as a composite product or used in combination with other materials in a composite application; meaning the ply contains layers or is layered over an acoustically reflective substrate [36]. Common designs consist of a rubber or foam core which has excellent sound absorptive properties and is then layered with a sheet of ply or face/ back veneers for decorative purposes. Depending on the visual application, acoustic ply varies from decorative for interior and visual purposes to outdoors (noise barriers) which are commonly painted. The thickness of the plywood panels is reliant on the application and final product target thickness where the core (insulation) will consume the majority of the thickness. This commonly results in a thickness range of 25 to 75 mm for the majority of acoustic ply globally. An example of acoustic ply is shown in Figure 4. (KEY CRITERIA: Visual appearance/ grade/ colour).

Figure 4: Example of noise barrier/ acoustic ply in use. Adopted from Procould [37].

3.1.6 Decorative ply

Decorative applications for plywood range across a number of uses from wall/ ceiling lining, cabinetry, furniture, door panelling, and composite products (e.g. blockboard); the majority of which are non-structural and commonly used indoors [33]. While not commonly exposed to direct environmental conditions, decorative plywood must still meet workability requirements for installation or for high use areas. These decorative products can be separated into three broad groups defined by where they are used.Table 3 details these groups as well as the technical, performance and aesthetic requirements (colour) for the intended applications. Some general properties that span across the three decorative ply groups include high quality visual appearance, smooth surfaces, and in some cases a coating to protect the surface (epoxy or polyurethane type coat or sealant). Examples of some interior ply panels are shown in Figure 5.

Table 3: Decorative group specifications for the various applications.

DECORATIVE PANEL TYPE	DESCRIPTION OF REQUIREMENTS
FURNITURE/ CABINETRY	The use of plywood for furniture and cabinetry spans across a wide range of product types, and with it a wide range of specifications for the product type (For example tabletops, chairs, kitchen counter, cabinets, etc.). For the general review of this product group, the key factors have been highlighted here. The bond type used for the products within this grouping is commonly Type B, C, or D where the applications with a greater opportunity for wetting or increased EMC should use a higher performing bond type. While the most commonly used thickness across counters, cabinets and tables is 16 mm, a range of other thicknesses from 1.5 to 32 mm is used depending on the application.
DOOR PANELLING (PLY DOOR AND BLOCKBOARD)	Door manufacture from ply/ veneers is undertaken through three different approaches; i) plywood is used through the total thickness of the door, ii) thin plywood sheets are used on the outside of a blockboard core, or iii) veneers are directly laminated to the outer surfaces of the blockboard core. As door panelling is a standardised dimension (width, height, and thickness) the thickness of the plywood used in i) and ii) are restricted to approximately 35 to 40 mm for i). Plywood used in approach ii) can range from 1.5 to 15 mm. Blockboard with veneer overlays is a less common door construction where the core in a solid sawn timber laminated construction with high quality veneers bonded to the face and back of the panel. As a non-standard construction, there is more flexibility regarding thicknesses for the blockboard and the veneers.
LININGS	Plywood used for lining of walls, ceilings and soffits provides two main application opportunities where one targets the aesthetic or visual appearance and the second being the use as both an acoustic and/ or fire-retardant barrier. The lining of a wall provides an opportunity to use high quality face veneers on the exposed face. As the panels often aren't required to offer any added structural performance to the integrity of the wall/ ceiling cavity, the product thickness is mainly driven by the accessory applications (e.g. acoustic and fire performance). Common product thicknesses range from 12 to 25 mm (<u>KEY CRITERIA</u>: Visual appearance/ grade/ colour, low roughness, and flatness).

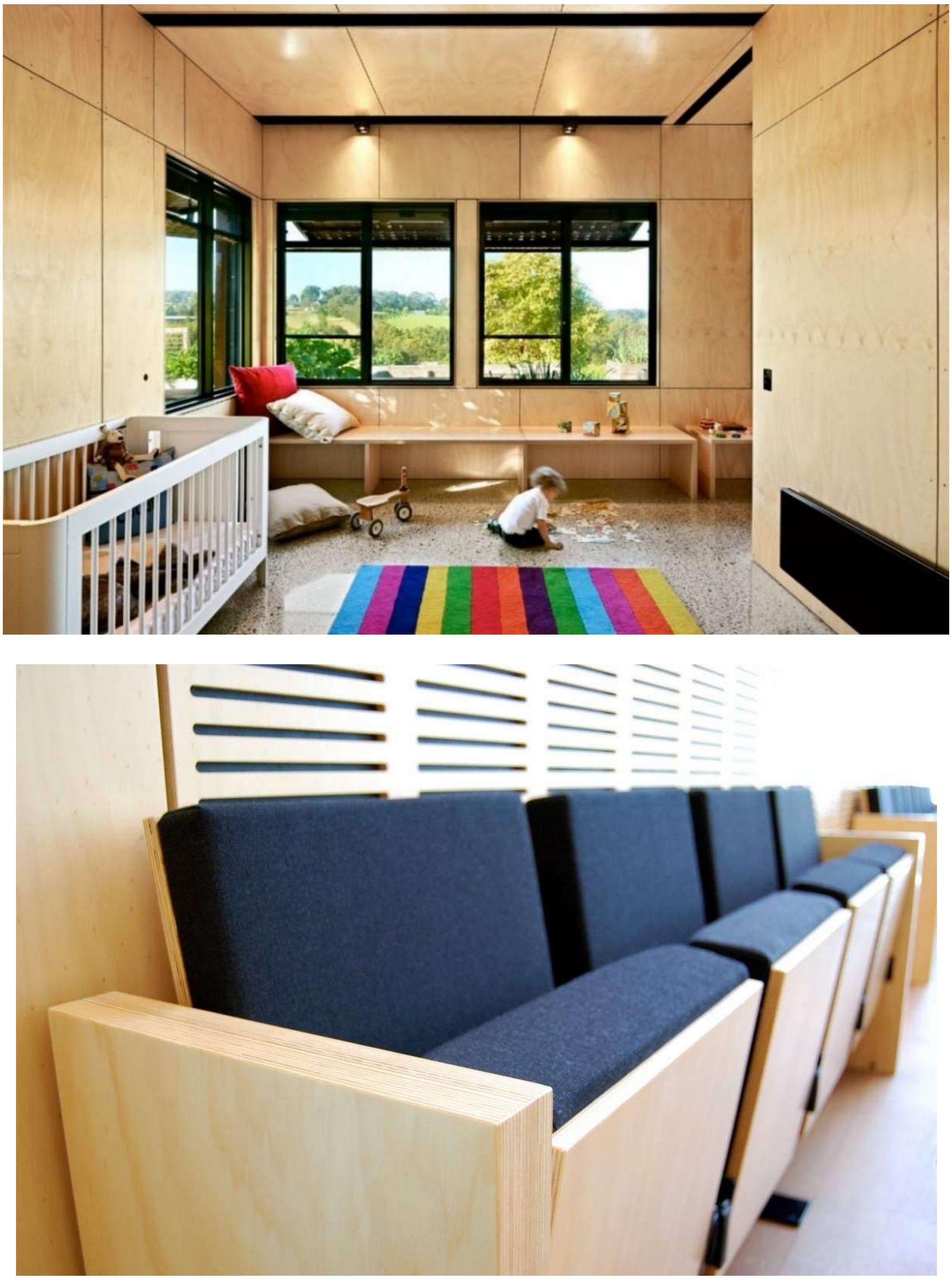

Figure 5: Decorative ply examples of celling and wall linings (top) and furniture usage (bottom) [38].

3.2 Laminated veneer lumber (LVL)

Laminated veneer lumber (LVL) was developed to compete with sawn material applications where a more consistent, defect free product was designed. Like plywood, LVL has a range of applications which can roughly categorised as either structural or non-structural groupings. Unlike plywood, LVL is considered a proprietary product and therefore does not conform to any specific grading scheme however is graded based on its application (i.e. for structural lightweight LVL joists/ lintels/ framing must conform to common stress grades such as an F grade from AS 1720.1 [39]). The testing conducted on LVL for mechanical properties determination follows the methods used for sawn boards with the added inclusion of bond quality testing (as does plywood) and assessment of formaldehyde emissions (if using a formaldehyde-based adhesive). This section defines the LVL product groups and key specifications/ characteristics inherent to that product.

3.2.1 Structural LVL

LVL used in structural applications is most commonly found in truss and frame manufacture, joists, lintels and bearers. These can vary from interior and exterior applications with some end-use applications requiring chemical preservative treatment. Structural LVL can been separated into two broad groupings, being structural lightweight LVL (joists, lintels, framing, etc.) and mass LVL. Table 4 details these groups as well as the technical, performance and aesthetic requirements for the intended applications. Visual veneer appearance grade is important for visually exposed products and while this is not a structural characteristic, the application of some structural LVL (if exposed) may require a high-quality visual grade on exposed faces. If this is not required, the visual appearance grade is not of concern as long as it does not affect other properties such as joint capacity, surface roughness and straightness. As a structural product, the following product groups are required to have a bond type suited to the application, usually an A-type bond. Figure 6 presents an example for the product groups described in Table 4.

Table 4: Structural LVL groups specifications.

STRUCTURAL PRODUCT TYPE	DESCRIPTION OF REQUIREMENTS
LIGHTWEIGHT LVL	Lightweight LVL has a broad range of product types including stumps/ posts, bearers, joists, noggings, studs, lintels, braces, and rafters. Lightweight LVL in most cases is not visible and therefore appearance is not of primary importance. In some cases, exposed beams for example, may require higher visual quality veneers on the exposes faces of the product. As introduced above, the stress grade assignment to an LVL beam is based on the application and as LVL is commonly used in place of sawn material, the grading rules governing sawn boards are used. As a results, there are a wide range of MOE grades available in the marketplace ranging from 6,100 to 21,500 MPa, although common grades used in lightweight framing generally range between 9,100 to 16,000 MPa. Veneer thicknesses vary between manufacturers, however, are usually between 2.5 to 5 mm.
MASS LVL	Mass LVL products are often produced by laminating sections of LVL on top of one another to reach the target depth/thickness, essentially as a 2-stage manufacturing process. These mass components can be used as either solid wall/ floor elements in structures (mid-rise timber structures) as an alternative to cross laminated timber (CLT), or for other speciality products such as timber bridge components. As these products are often made from lightweight LVL feedstock, the requirements are similar to those of sawn material or the governing standard for the products application. Depending on the expected exposure conditions, coatings and sealing systems may be required. (<u>KEY CRITERIA</u>: Mechanical properties, low roughness, and flatness)

Figure 6: Structural LVL product example. Adopted from Zealand [40].

3.2.2 LVL Formwork

LVL used in formwork applications has identical design and performance requirements to plywood (Section 3.1.4). Specifications such as target density, smooth surface finish and bond quality are all consistent with the requirements for formply products. The requirements for LVL in this grouping do not differ from those of plywood (formply). (KEY CRITERIA: Low roughness, straightness, mechanical properties, and density).

3.2.3 Decorative LVL

Decorative applications for LVL range across two broad groups – furniture/cabinetry and, doors and windows. The majority of decorative LVL products do not demand structural performances and are commonly used in indoor applications. As a visual product, the appearance is of primary importance to the product application. Table 5 details these groups including the technical, performance and aesthetic requirements. Figure 7 presents a series of examples of the applications discussed in Table 5.

Table 5: Decorative LVL groups specification.

DECORATIVE PRODUCT TYPE	DESCRIPTION OF REQUIREMENTS
FURNITURE/ CABINETRY	The use of LVL for furniture and cabinetry spans across a wide range of product types and applications (cabinet framing, bed slats, chair components, etc.) with products varying considerably. As such only the general specifications have been highlighted here. Commonly used thicknesses vary between 1.5 to 32 mm. LVL (presenting an alternative to solid sawn material) can be employed to present the veneer layering as a decorative feature. Because of this, some applications may call for thinner veneers to be used meaning veneer thicknesses range from around 0.8 to 3.0 mm.

DOOR & WINDOW FRAMING	Door/ window frame manufacture using LVL is undertaken through moulding in a similar manner to how a sawn board would be moulded or machined for door/ window jambs and framing. Exterior doors and windows present areas that experience great moisture exposure and also great variation within the product. Therefore, this product requires good dimensional stability which is influenced by both the timber (veneers) and the adhesive type. While various bond types could be used, global manufactures of LVL used in door and window frames adopt a high-performance bond type (usually A-bond). (KEY CRITERIA: Visual appearance/ grade/ colour, low roughness, and straightness).

Figure 7: Decorative LVL product type examples [41].

3.3 Other wood products

3.3.1 Particle-based

While the term particle or fibre-based can refer to a number of wood-based composite panels (e.g. particleboard, medium density fibreboard – MDF, oriented strand board – OSB) their manufacturing process has some similarities [3]. The majority of these products are commonly manufactured using residual waste generated from other processing plants. The processed particles are sorted based on size before being bonded together with resin and pressed into the form of a panel [3].

Particleboard, MDF and OSB essentially vary only in the particle size used. For example, particleboard commonly uses a particle size ranging from 0.5 to 4.0 mm, whereas MDF is made from much smaller particles and OSB used larger 'flakes' of wood. Particleboard has a relatively low bending stiffness ranging from 2.1 to 3.0 GPa, which can limit its use to short spanning floor sheeting (underlay) or cabinetry. Particleboard is commonly a 3-layer product where the core is made up of course large particles and the faces made up of small particles. Particleboard is commonly produced to thicknesses between the range of 16 and 33 mm. The product stability and resistance to moisture uptake can be further improved through the addition of additives (waxes etc) to the manufacturing process.

MDF can be used in a visual application (in speaker boxes for example) due to its smooth finish. It also has a bending stiffness range of 1.35 to 3.13 GPa. MDF is often used in the same applications as particleboard, with 57% of the material being used globally in furniture, joinery, and cabinetry [42]. The smaller fibre size (32 to 62 µm) also allows for MDF to be cut, sanded and routered to offer a smooth decorative finish – a key benefit over particleboard. The average density of MDF panels range from 700 to 800 kg/m^3 and common thicknesses range vary from 6.5 to 19 mm, although the global availability can range from around 1.8 to 60 mm. A limitation of MDF and particleboard is their bending strength and stiffness which limits the use of this product type in many applications. This is due to the short fibres being solely reliant on the resin to hold the panel together when exposed to stress [7].

OSB's strength comes from the improvement in uninterrupted fibres which interweave the long strands together (range of 2.5 to 4.8 GPa for MOE). This coupled with the strand orientation and layering allows for a series of scenarios where the fibres interlock with each other [7]. According to the European panel federation [43], OSB is most commonly used in construction applications as either a cladding, flooring or composite (I-beam webbing) material type. Its surface finish is not commonly considered appealing and is therefore not regularly used in applications where it is visible. OSB commonly ranges in thickness between 6 to 25 mm. OSB can be made moisture resistant through the use of a moisture resistant resin systems during manufacture. The finished panel density commonly ranges from 600 to 680 kg/m^3. Some examples of the discussed product types are displayed in Figure 8. (KEY CRITERIA: fibre/ particle size, density ranges, surface finish (roughness and flatness)).

Figure 8: Particle-based product examples (Left – particleboard, Right – OSB).

3.3.2 I-beams

I-beams (also referred to as an I-joist) are a composite EWP that consists of top/ bottom flanges and an interior webbing. I-beams are commonly produced with LVL flanges and either a ply or particle-based web. Used commonly as bearers/ joists, I-beams are a structural element which can substitute for sawn timber and provide lightweight, high stiffness and dimensionally stable benefits [44]. As these are not commonly visible in the finished building, the visual appearance is not a primary feature and thus low-quality veneer, or surface appearance of the web can be acceptable.

Commonly, MOE for product applications globally range from 9,100 to 16,000 MPa, although other variations are possible depending on the requirements. Web thicknesses commonly range between 6 to 12 mm, although other variations are possible depending on the application. (KEY CRITERIA: mechanical properties, thickness, and flatness).

3.4 Suitability

From the product types identified in the global marketplace and the key selection criteria highlighted, Table 6 has been developed by overlaying the market driven product performances and an understanding of cocoveneer properties to identify product suitability. This process has been developed to determine product groups that may or may not be suitable for cocoveneer material to be used in. The analysis presented in Table 6 is based on specific criteria weighting based on the product application where this weighting matrix can be found in Appendix A. The products have been scored between 1 (very unlikely) to 5 (very likely) as to the likelihood of the product's success in the marketplace when made with cocoveneer material.

The ranking presented in Table 6 is based on the literature collected and referenced through this report as well as the authors' knowledge and expert opinion. A description has been added to the product groups with a general comment on the decision of suitability as well as some key product discussion.

Table 6: Table of products for the suitability of cocoveneer.

PRODUCT GROUPS	SUITABILITY RANK					
	1 (Very unlikely)	2 (Unlikely)	3 (Possible)	4 (Likely)	5 (Very likely)	COMMENTS ON RANKING DECISION
(SECTION 3.1) PLYWOOD TYPES (SECTION 3.1)						
BRACE PLY						Bracing plywood has reasonably strict market requirements for panel thickness (usually below 7 mm). Due to veneer processing limitations that necessitate thicker than normal veneer production, manufacturing a panel within the required thickness for bracing plywood using cocoveneer is very unlikely.
FLOORING						Based on cocoveneer's reported density and its visual appearance (especially for mid- and high-density veneers), it is considered very suitable for flooring products. The specific sub-category suitability is discussed below.
FORMPLY						Due to the strict surface finish requirements of formply (requiring a very smooth surface finish), it is unlikely cocoveneer would be suitable for the manufacture of formply. An opportunity could exist to used cocoveneer as core veneers only and using different veneers as face veneer, depending on the mechanical properties required of the product.
ACOUSTIC						The weighting of acoustic ply favours the visual criterion for the external faces, as the product is usually a composite product including some foam (or other similar material) layering. It is considered likely that cocoveneer or cocoveneer EWPs would be suitable for this application.

DECORATIVE		While the description of decorative ply outlined several applications, their assessment criteria/ requirements are relatively consistent. Cocoveneer is considered to be very likely suitable for decorative furniture ply applications due to its striking and unique visual appearance.
LVL TYPES (SECTION 3.2)		
STRUCTURAL		Cocoveneer is considered likely suitable due to its achievable stress grade ranges in line with the requirements of structural framing and mass panels.
FORMWORK		Similar to flooring plywood above.
DECORATIVE		Similar to decorative plywood above.
OTHER WOOD PRODUCTS (SECTION 3.3)		
PARTICLE		Based on the target fibre size and that of cocofibre, OSB and particleboard are considered likely suitable. Traditional scale of manufacturing requirements are not likely to suit Fiji and other Pacific Island countries. The specific product types suitability is discussed below.
I-BEAM		Based on panel shear performance reported by MCGavin, et al. [27], it is unlikely that cocoveneer EWPs would make a suitable I-beam production.

Prototypes introduced through this report have been designed, manufactured and tested as part of the current or previous projects (referenced throughout this report) focusing on cocoveneer EWP types. This provides further justification to support the analysis presented in Table 6. Images have been supplied as exemplar material where available. From the requirements detailed in sections 3.1.3 and **Error! Reference source not found.**, along with the weighting matrix above and in Appendix A, not all veneer resource recovered from coconut palms would be suitable for flooring. The flooring groups suggest a number of criteria to be of key importance depending on the application. Underlay flooring must have both some structural capacity and density to ensure it performs as required. Although as it is an underlay product (non-visual), its appearance is less critical. Overlay products are commonly applied to the floor substrate or underlay and are generally not considered structural (as shown by the weighting difference in Appendix A). Overlay products require a specific hardness rating with an increased importance in visual appearance, surface roughness and flatness. Flooring grade timber products (plywood, tongue and grove (T&G) boards, overlay) require a hardness (depending on the service conditions) of approximately 5 to 6 kN or greater. As introduced in earlier sections, hardness has been proven to correlate closely with density [16]. From the peeling trials conducted by McGavin [24] the estimated recovery of material that meets this criterion is approximately 46%. In addition to density, the visual appearance is more subjective and would be dependent on the customers preference. Example of flooring produced using cocoveneer is presented in Figure 9.

Figure 9: Cocoveneer flooring products.

The flooring products discussed in sections 3.1.3 and **Error! Reference source not found.** have been separated into visual and non-visual products (overlay and underlay), although these could be further divided into groups of high and low traffic or potentially residential and commercial use. While their general requirements will remain similar, a low -use residential floor (e.g. bedroom) may allow for lower density material than what would be required for a commercial high traffic floor (e.g. reception foyer).

The density variations of coconut wood produce a range of stress grades which could be applied to suit a range of structural products (both plywood and LVL). Product design and development could be used to manipulate the high to low density veneers to achieve acceptable stress graded products in a similar form to the methodology presented in McGavin *et al* [45]. The mechanical property testing reported by McGavin *et al* [20, 27] has been limited to a preliminary set of product types, test methods and sample numbers. More detailed testing and characterisation of the material would be needed to confirm its suitability for structural use. Examples of structural products (plywood and LVL) are displayed in Figure 10.

Figure 10: Structural cocoveneer EWPs: plywood (left) and LVL (right) products.

Based on the applications of most structural products, there is a low requirement for visual quality, therefore these products commonly are able to more easily accommodate low visual veneer grade. While cocoveneer EWPs can meet the requirements of a structural product its marketability appears to reside with the materials appearance; applications where this is not optimised may result in poor market uptake.

Based on the specifications detailed in Section 3.3.1, the particle sizes for OSB and particleboard appear more aligned with the fibrous structure of cocofibre. Fibres required for MDF are considered too fine for the production to be possible with cocofibre. Furthermore, particleboard and OSB allow for the novelty of the grain pattern to be highlighted in the design. Regardless, the product performance is still unknown and would require characterisation prior to a firm decision being made. Specifically, its final surface appearance and quality (roughness) will be important. Initial product development has been conducted and is presented in Figure 11.

Figure 11: Cocofibre particleboard product example.

Some decorative cocoveneer products have been trialled (Figure 12) which highlight the uniqueness of the material. The three examples show the materials used in a range of applications with Figure 12 (a) on a small scale as a drink coaster with a single cocoveneer overlayed with a traditional plywood substrate. This allows for a cost-effective product to be designed while still meeting the key appearance decision criteria of a furniture/ decorative product. Figure 12 (b) presents a product which has been sawn from a larger block of cocoveneer LVL. Figure 12 (c) showcases cocoveneer being used as the decorative face for a door, covering the low quality-low cost blockboard.

(a) (b) (c)

Figure 12: Decorative cocoveneer examples (a) cocoveneer drink coster, (b) multi-laminate cocoveneer slice panel, and (c) blockboard door with cocoveneer overlay.

The market desire requirements of both formply and LVL formwork suggest that cocoveneer may be suitable for its development if the surface roughness is kept relatively low. This market requirement of surface roughness is less critical for LVL formwork. This surface roughness will govern the achievable grade of the formply, and the consequential value. The critical aspect of the surface layers or cost of production from a 100% cocoveneer product can be mitigated through blending with other species (smooth, easy to peel veneers added to the surface or low-cost, low-grade material as a core). Conversely, there are a number of additional factors to consider other than the materials alignment with the selection criteria of the product. As highlighted above, the appearance of cocoveneer EWPs is one of the primary qualities that makes the product manufactured with it unique and aesthetically appealing. Products where the material is visible are considered the optimal application, so formply and formwork LVL may not be the best market to pursue in order to maximise value, at least not for the more sort after veneer qualities. LVL for light construction (e.g. framing, lintels etc) provides another scenario where cocoveneer EWPs are unable to capitalise on its most unique property. Based on the product examples presented in Figure 9 through Figure 12, and data summarised in Section **Error! Reference source not found.**, it is evident that there is suitable information available to support the manufacture of cocoveneer EWPs. However, it is noted that the majority of this information is technical in nature and has limited concerns for other factors such as size and accessibility of the market or influence of competitor products etc.

4 Industry Consultation

The following section has been formulated to assist in defining a product with an available market for production and use in Fiji. To confirm or correct the information obtained through Section 3.4, an engagement and consultation study was conducted across Fiji for some selected industries. A total of 25 companies were selected across four major cities and towns of Suva, Nadi, Labasa, and Savusavu. The companies were identified and interviewed to obtain a cross-sectional understanding of the industry in Fiji. The companies and their roles captured in this review included timber product manufacturing (plywood production), construction firms, joinery and cabinetry fitters, and importer/ exporters. The key outcomes of these interviews are presented through this section. The questions used during these interviews are noted in Appendix B.

4.1 Market consultation

To gain an understanding of the potential market for cocoveneer EWPs in Fiji, 25 Fiji-based companies were selected and interviewed. These companies included representation from a range of industry sectors including cabinetry and joinery, construction, veneer processors and EWP manufacturers, exporters and importers, and furniture producers (Figure 13).

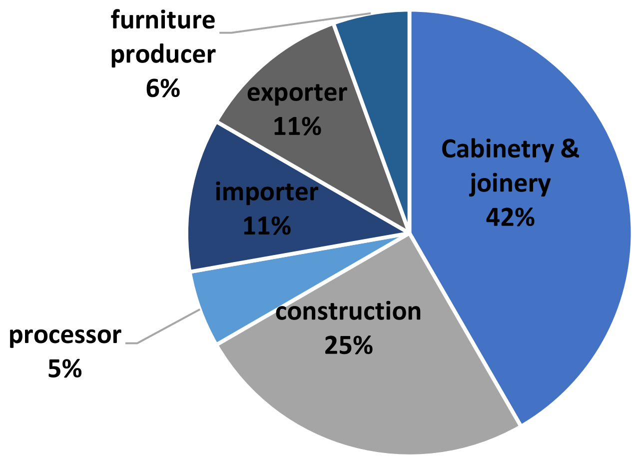

Figure 13: Distribution of industry consulted in Fiji.

It was observed that the majority of businesses provide two or more services; for example, a construction company will often have their own cabinetry and joinery labour. Cabinetry/ joinery, and construction sectors represented 67% (42 and 25% respectively) of the businesses interviewed. This bias resulted from the product analysis (discussed above) which suggested likely products will be predominately used by these sectors.

4.2 Available timber materials

Consultation first involved developing an appreciation for what wood-based products each business traditionally use. Figure 14 presents an overview of the market share of wood products commonly used across Fiji, based on these consultations. From this analysis, it can be seen that plywood and other such veneer-based products make up 62% of the materials used in construction, joinery, etc. in Fiji. This is at least partially due to plywood being the only EWP currently being manufactured in Fiji. MDF is also commonly used in Fiji for kitchen fit-outs (cabinetry, countertops) with some form of overlay (veneer or melamine),- this product being 100% imported. Glulam is only used in limited cases if the project specifically requires it (client driven) and is also 100% imported. From the interviews, it was suggested that LVL is not used in Fiji.

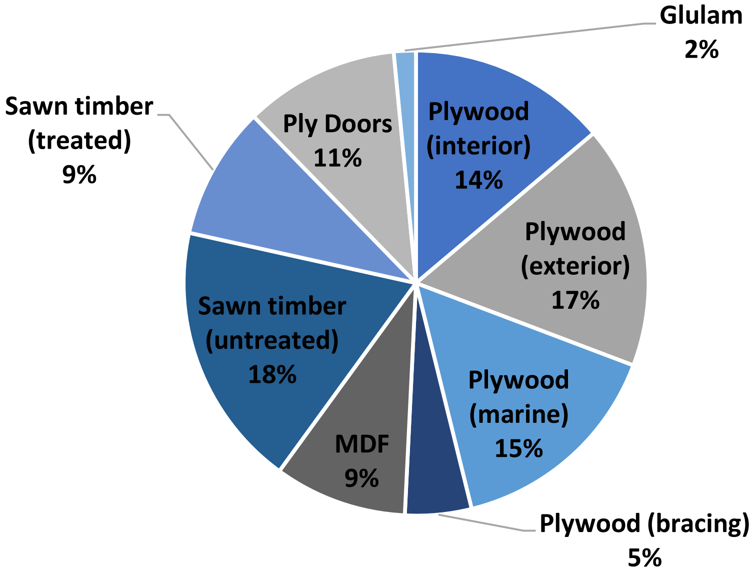

Figure 14: Distribution of material available in Fiji.

4.3 Veneer-based product applications

The analysis presented in Figure 15 shows how veneer-based EWPs (i.e. plywood) are used in Fiji. Structural plywood products account for approximately 25%, whereas the remainder of the product groups (75%) do not demand specific structural performance. The groups which had higher representation included cabinetry (18%), countertops (14%), flooring (overlay) (12%), furniture (12%) and doors (12%).

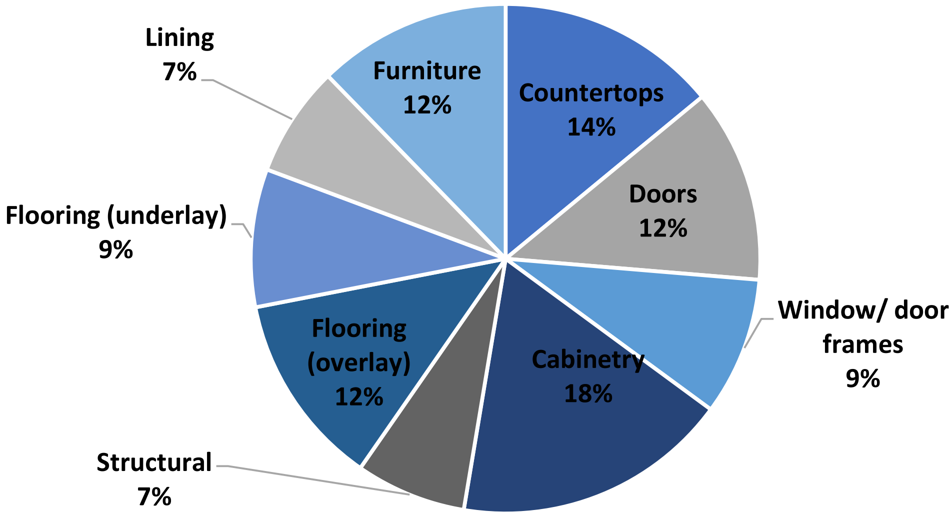

Figure 15: Proportion of veneer-based product types used in Fiji industry.

4.4 Applications for cocoveneer EWPs

As part of the industry interviews, the interviewees were asked their opinion of the potential use of cocoveneer EWPs and which products were perceived to be most suitable. Samples of cocoveneer and product examples were provided to stimulate discussion and ideas. The companies interviewed were asked the following questions:

- What key attributes about cocoveneer do you believe are attractive to potential markets and why?
- While potentially technically suited for both structural and non-structural applications, where do you see the best product opportunities for cocoveneer EWPs and why?
- Of the timbers products you produce, use or sell, do you see cocoveneer EWPs being able to be a substitute for any of them?

Based around these questions, a discussion followed with focus on the potential to use, produce, trade cocoveneer and/or cocoveneer-base EWPs. In addition, potential product applications were considered which proved to have a dominating focus towards non-structural markets (95%) compared to structural markets (as shown in Figure 16). Within the non-structural market group, the suggested applications included flooring overlay (22%), cabinetry (17%), and door/ window framing (15%).

While flooring overlay, cabinetry and framing (windows and doors) were the most favoured responses, doors, veneer overlay faces, and furniture were closely ranked (12 to 10%). The visual qualities unique to cocoveneer EWPs provide a point of difference for the marketability if the application is visual. Instances where the product would not be visible (underlay, light construction framing etc) may be technically possible but may not provide sufficient market demand or value adding opportunities.

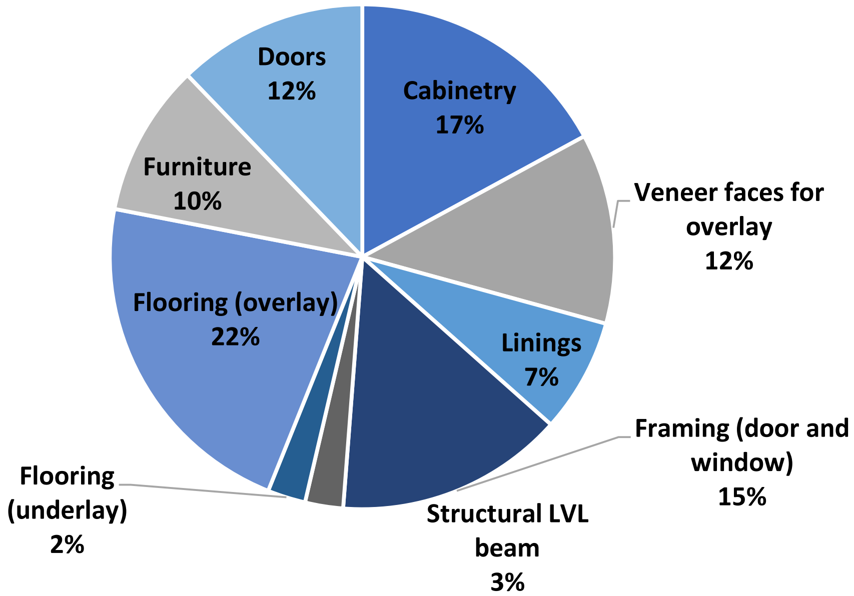

Figure 16: Industry opinion of the potential end-uses for cocoveneer EWPs.

4.5 Perceived challenges for cocoveneer EWPs market access in Fiji

In addition to discussing the potential applications for cocoveneer EWPs, the perceived challenges were also discussed with the interviewees. Figure 17 presents the 7 main responses received during the interviews. These responses were both product specific (concerns with the materials ability to meet the performance criteria), and material specific (durability, treatability). The key concerns were related to final product cost (21%), suitable durability (18%), potential to preservative treat or treatability (18%), suitability of the appearance (14%) and challenges with workability (14%), and specifically how the potential products would perform in the harsh Fijian climate. Some interviewees suggested the high-density material was 'busy' looking and therefore may not be suitable for large surface areas. Workability was a concern from an installation point of view (sanding, sawing, screwing, drilling) and how the surface veneer would perform during this process.

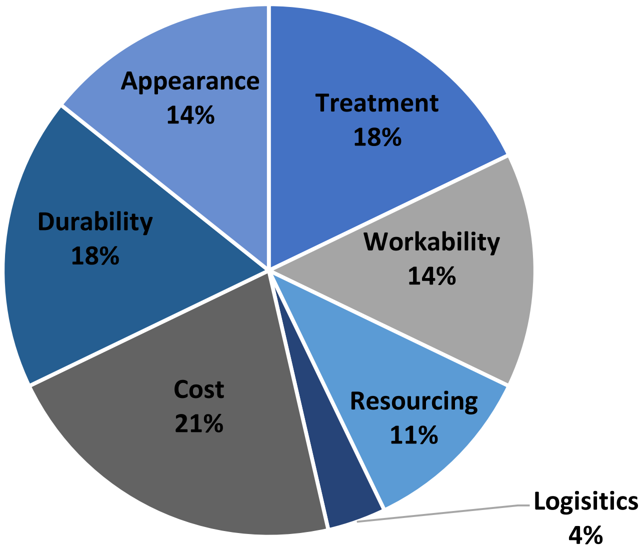

Figure 17: Challenges and concerns raised by industry for cocoveneer EWP adoption.

4.6 Product price analysis

From the challenges raised, price comparisons with other market available products were considered high priority for almost all interviewees. The following section provides summary analysis of Fiji market plywood prices obtained from the Fiji commerce commission [46]. The data collected from this document included plywood product types (exterior and interior only reported), thickness ranges, and prices per sheet. It should be noted that the prices reported here are the wholesale amounts. Figure 18 presents the market thicknesses and product (irrespective of species) types currently available. The amounts discussed through this section refer to Fijian dollar amounts (FJD).

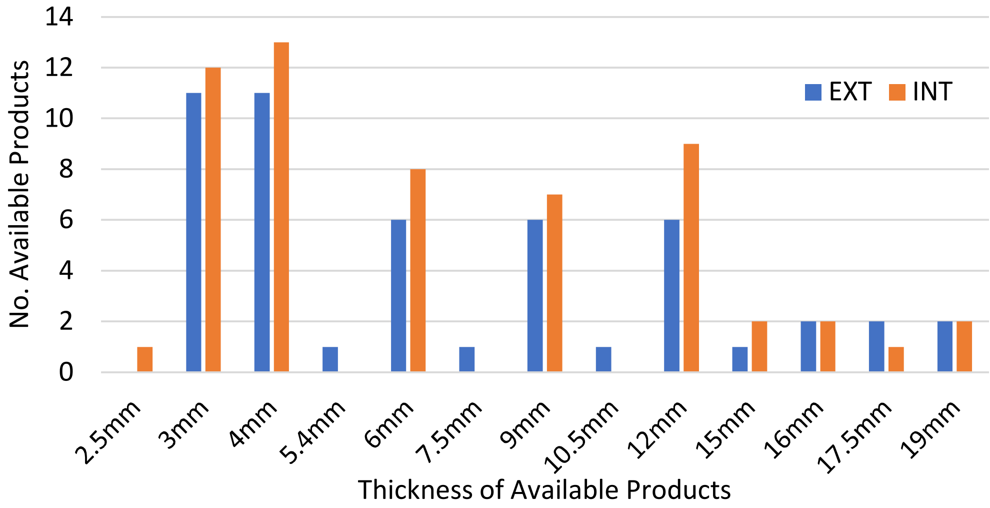

Figure 18: Market available thicknesses and product types.

From this information, it appears there is a larger number of products for 3 mm, 4 mm, 6 mm, 9 mm and 12 mm thick plywood. Based on the known limitations of cocoveneer processing and that products less than 9 mm are unlikely, it could be suggested that a 9 mm and 12 mm product would cover the demand in Fiji. It is also understood most countertops and cabinetry materials require 16 mm thick plywood. Figure 19 presents the wholesale price associated with the plywood thicknesses and product types as introduced above.

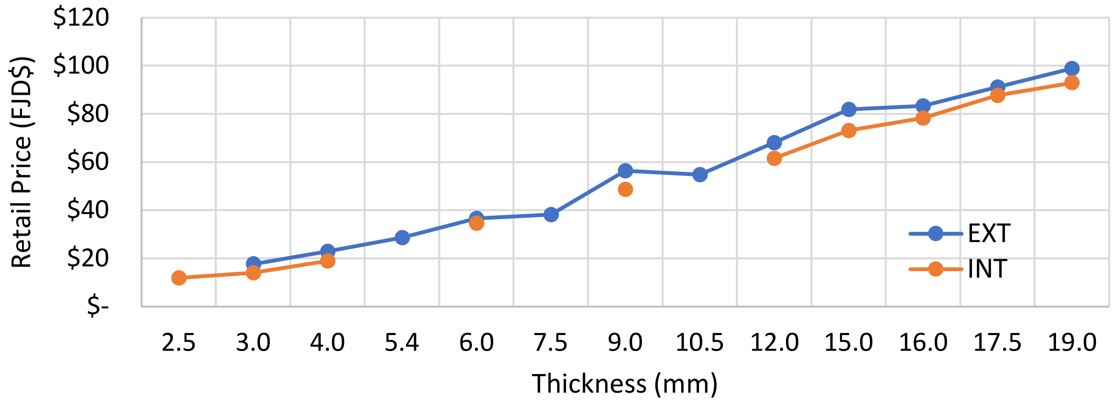

Figure 19: Wholesale prices for plywood (internal and external grade) at varying thicknesses.

As the suggested product thickness range (taking market interest into account) is 9 mm to 12 mm the current wholesale price for these products (wholesale) ranges from (FJD) $34.93 (9 mm interior grade plywood) to (FJD) $73.20 (12 mm exterior grade plywood). The wholesale price for 16 mm plywood (both exterior and interior) ranges from (FJD) $75.81 to (FJD) $85.98 where the range is linked to the interior or exterior rating.

5 Conclusion & Recommendations

The aims and objectives of this review had been to report on the globally available groups of veneer-based wood products, their various applications and key performance criteria. Through expert knowledge and opinion, and a robust literature review, the product descriptions and criteria was detailed in order to allow for suggestions of suitable groups where cocoveneer EWPs could be substituted. This desktop investigation was complimented with an in-country industry consultation phase where 25 companies were interviewed to gain an industry perspective of cocoveneer EWPs.

The desktop investigation identified a total of 22 product groupings which were comprised of 11 plywood-based, nine LVL-based, and two other groupings (particleboard and I-beams). These groupings cover a range of applications including internal or external use, structural or non-structural, and visible or non-visual, etc. For each of the product groups, the key design or market driven performance criteria were described. These product groups combined with the literature review conducted on cocoveneer and cocoveneer EWPs highlighted potential opportunities where cocoveneer EWPs could be used in conjunction with or as a substitute for other traditional materials. The analysis and industry interviews identified that the visual qualities unique to cocoveneer EWPs provide a point of difference for the marketability. As a result, seven product groups were considered as either 'likely' or 'highly likely' to be suitable for cocoveneer EWPs. These product groups were biased non-structural products and those that demanded and valued visual characteristics. To validate the results of the desktop analysis and further refine the proposed product groupings, Fiji-based industry consultation was conducted (November 2022). A selection of companies were interviewed for their interest in cocoveneer EWPs as well as opportunities for its use through substitution for a product(s) they currently produce, market or use. Outcomes of this process echoed the desktop investigation where 95% of suggested product groups for cocoveneer EWPs were in non-structural visual applications, such as flooring overlay, cabinetry, and window and door framing (finishings). Perceived challenges and/ or risks in cocoveneer EWPs entering the market were highlighted by industry with the majority of the interviewees considering cost competitiveness, durability, treatability and workability as issues worthy of further consideration.

Acknowledgements

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Appendix A: Product Criteria Weighting

The information and decisions presented in Table 6 are based on the following weighting matrix detailed in Table 7 which specifies the key selection criteria for the reviewed products in Sections 3.1, 3.2, and 3.3. The percentage weighting that is reported in Table 7 is based on the description of the product groups and expert knowledge. This table highlights the key characteristics that are considered for whether cocoveneer EWPs are a suitable supplementary material for the application.

Table 7: Selection criteria weighting matrix.

Product Type	*Selection criteria*				
	Thickness	**Mechanical props**	**Density**	**Roughness, flatness & workability**	**Appearance grade (colour)**
Bracing ply	4	2.5	2	1.5	0
Flooring ply					
- (Underlay)	1.5	3	4	1.5	0
- (Overlay)	0.5	0.5	4	2	3
- (Vehicle ply)	2	0.5	4	2.5	1
Formply	1	2	2	5	0
Acoustic ply	1	1	2.5	2.5	3
Decorative ply					
- (Furniture)	0.5	0.5	2	3	4
- (Doors)	2	0.5	0.5	3	4
- (Linings)	1	1	1	3	4
Structural LVL					
- (Framing)	1	5	1	3	0
- (Mass panel)	1	5	1	3	0
LVL flooring					
- (Underlay)	1.5	3	4	1.5	0
- (Overlay)	0.5	0.5	4	2	3
LVL formwork	1	2	2	5	0
Decorative LVL					
- (Furniture)	0.5	0.5	2	3	4
- (Door/ window frame)	2	0.5	0.5	3	4
Particle-based					
- (Particleboard)	1	1	3[1]	3	2
- (OSB)	1	1	3[1]	3	2
- (MDF)	1	1	3[1]	3	2
I-beams	1	4	2.5	2.5	0

[1] The density weighting here also includes the importance of fibre size for the particle-based products.

Appendix B: Industry Interview Questionnaire

1) What are your top 3 product types you use/ sell/ manufacture in terms of market demand?

   a. (If these are not timber products) At what level does your highest value timber product sit on this list?

   b. (For timber products only) please detail the product type (species, adhesive used if applicable, construction type),

Species:
Adhesives (if applicable):
Application/ Construction:
Grade(s):
Material Type:

<u>All following questions will be specific to timber product types the respondent deals with or manufactures.</u>

2) (Producer only) What equipment do you have on site/ capacity for producing wood products?

3) Has demand increased/ decreased over the past 5 years here in Fiji?

   a. (Producer) Who are the main customers/ users of this product?

   b. (Construction company) What are your main client source (residential, industrial, commercial, holiday/ resort)?

c. (Importer) Do you have any details of the market demand where this project originates?

4) Have costs increased/ decreased for purchasing these products or the raw materials over the past 5 years?

a. Do you have any thoughts as to the reasoning and cause of this change, if any (freight, demand, etc.)?

5) What promotion or marketing do you conduct for these timber products?

6) What are the perceived challenges and risks of the company?

7) Is the resource/ product you purchase plentiful? Meaning is there any threat or risk that this product may become difficult to come by in the future?

8) Have you considered alternatives to your current product range (alternative species)?

9) Would you ever change resource type if the criteria were aligned with your current resource and product types?