Forest&Wood Products Australia
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MARKET ACCESS & DEVELOPMENT
PROJECT NUMBER: PRA154-0910
APRIL 2011

A market assessment and evaluation of structural roundwood products from hardwood pulp plantations

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Prepared for

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Publication: A market assessment and evaluation of structural roundwood products from hardwood pulp plantations

Project No: PRA154-0910

ISBN: 978-1-921763-22-9

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Final report received by FWPA in April 2011

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Executive Summary

Hardwood plantations comprised of *Eucalyptus* species have been established on a range of sites around Australia for pulp and paper fibre on short rotation management systems. Simultaneously with the increased area planted under pulp regimes, access to natural hardwood forest stands has been reduced, a trend that will continue in most Australian states in the foreseeable future. Plantation owners are interested to know if pulp plantation material has the potential to produce a higher value crop than the original wood chip product and meet the shortfall developing from reduced availability of natural forest resources.

Roundwood structures have always been used for temporary and low cost shelters and other fleeting structures. Novel concepts for the use of plantation hardwoods in roundwood form in construction were developed and circulated along with an electronic questionnaire to stakeholders representing growers, designers and users of hardwood. Responses indicate that there is a high level of interest in developing products from the emerging small roundwood resource and a detailed program of research was supported and recommended by the majority of participants in the survey.

It generally isn't feasible to process pulp logs through traditional sawmilling equipment due to the low recoveries obtained; however this material has the potential to provide high value products in roundwood form. Roundwood products have a range of advantages over sawn boards such as: improved strength attributes for equivalent cross-sectional area; reduced processing costs, lower embodied energy and reduced wastage due to minimal processing activities. Simple steaming technologies can be used to prepare roundwood stems for bending around a form to produce arched structural members providing a wider range of design options to users.

Examples of potential markets include: noise barriers and wind barriers, niche architectural buildings, national park and local authority shelters, ablution facilities and viewing platforms, rural buildings, light footbridges for walking trails, golf course and suburban parklands' infrastructure.

Although roundwood products are widely used in fencing and landscaping applications, their usage in applications such as the concepts listed above represents the introduction of novel and therefore untried systems. The goal of this project was to investigate potential market interest for innovative applications using small diameter roundwood such as pulp logs and thinnings from sawlog plantations.

Senior architecture students from the University of Queensland were presented background information on hardwood plantations, principles of wood science and elements of timber design. Using this information and with support from their lecturer they worked individually and in teams to produce designs and models for roundwood structures.

Illustrations of a selection of these concepts representing small scale (shelters), medium scale (remote housing), large scale (industrial buildings and infrastructure (sound barriers) were included in an electronic survey which was emailed to over 1,200 stakeholders representing a broad cross section of forest growers, designers, specifiers, engineers, timber industry representatives and users.

The results from the survey provided an optimistic view for the potential of small, roundwood, structures with 87% of respondents indicating that they liked the overall impression of the designs and concepts, versus 13% who were neutral. Encouragingly, no respondents disliked the overall impression based on the concepts supplied.

When considering each of the four size class concepts separately, the majority of respondents ranked the general appeal in each case as appealing to very appealing.

The best potential for market uptake was considered to be small shelters and infrastructure, with 80 % of respondents considering the potential for commercialisation of these two construction types to be medium or high.

When asked whether they considered that more detailed research and development is warranted or justified 97% of respondents support or fully support further exploration, with 3% neutral.

An economic assessment was undertaken in relation to the benefit of further R&D and showed that the net present value of R&D investment is high, increasing the viability of hardwood plantations through commercial use of sawlog thinnings and higher value products from pulp plantations. Using a 5% discount rate, the internal rate of return was estimated as 492%, the benefit cost ratio 223:1 and the net present value $100M.

These results indicate a high level of support for further investigation into the use of plantation hardwood for roundwood components. Respondents representing a wide range of stakeholders have indicated that to gain benefit from a detailed project they would require solutions for connection systems and protection from pests and weathering, indications of cost and assurance of ongoing supply for niche applications, data for strength, acoustic dampening and thermal insulation properties, acceptance by regulatory authorities and training for on-site construction.

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Introduction

The development of extensive forest plantations under the “National Forestry Policy Statement” and the “Plantations for Australia: The 2020 vision” have attempted to secure a longer term sustainable industry for construction and other timber products. Though the established end user industries provide growers with some certainty as to the potential yield of plantations at the end of their life cycle, more can be done to leverage extra value from the plantations throughout the management cycle. One important aspect of this cycle is the use of thinnings. Currently this resource is used for lower value applications such as pulp, firewood and low grade timber products. Research around the world has shown that if thinnings can be used in viable higher value applications in the construction industry then the yield from plantations could significantly increase and hence the financial return to the national economy.

Plantation crops of hardwood species have been established under two general management regimes, dependent on final products and markets. The majority of hardwood plantation area has been managed for pulp fibre over a short rotation period, with a lesser area for sawlog over a longer rotation period. In the latter case, it is usual practice to thin to waste a proportion of trees to avoid them competing with superior stems. The age of the trees at the time of this thinning operation may be similar to the final crop harvest age in pulp plantations. This report discusses the opportunities for diverting these thinnings and pulp fibre trees to a higher value application which may increase the economic return from hardwood plantations. It summarises the work of a limited scoping study into the possible application of hardwood thinnings from plantations. It focuses on processes that can both help the seasoning of the wood and the aesthetic and form making potential of steam bending the thinnings into defined curvilinear geometries. Within the limits of a scoping report, this study has focused on the possible end user applications and prototype designs to test market perceptions and desire for further research. A detailed program of research in this domain would likely fast track the benefits to growers.

The report is broken in several main areas. Prior research is outlined in the methodology section. Key projects are themes are identified that have guided the rest of the project. A description of the resource and the approach to developing and assessing ideas has been included in the methodology section also. The main research was undertaken as an inquiry through design. The design propositions were developed by master’s level architecture students at the University of Queensland. The reporting on the process and findings from the design exercise is outlined in the results and discussion section of this report. The proposals developed by the students have been catalogued in the appendices 3 to 5.

Designs were generated with advice and feedback from industry experts. Early designs were presented for review and these in turn were edited down and developed through large scale model making. Experiments at 1:1 including the trial bending of some stems was undertaken to widen the perspective of the report across all scales of understanding. Outcomes from the design exercises were summarised in a report that was circulated to industry to gauge opinion via an online survey. A detailed breakdown of the survey results are itemised in the results and discussion chapter with the content of the survey and the full breakdown of responses itemised in appendices 1 and 2. An economical assessment was conducted to estimate the benefit of undertaking a detailed research and development (R&D) project on plantation hardwoods for structural roundwood.

The report summarised key finding and importantly highlights those aspects of the study that require further investigation. One should always bear in mind that this is a scoping study and the aim is to both explore the potential as well lay out the breadth of further study required. We believe that this report more than adequately demonstrates the potential of the resource but equally acknowledges the extensive and broad ranging work that is required to turn great expectations into market realities.

Methodology

Given that the aim of the project was to demonstrate the breadth of design potential for structures that utilised steam bent roundwood thinnings the approach taken was to lead the inquiry through the design of prototypes and to then gauge the level of industry interest in these structures. Consideration of prior research and design constraints were taken into account at the start of the design phase. The project was undertaken by Master of Architecture students enrolled in the School of Architecture at the University of Queensland. The group of 15 students was led by two academics from the school, Mr Michael Dickson lecturer in design and technology and Mr Tim O'Rourke, PhD candidate in the field of Indigenous settlements and construction. Students worked individually and in small groups to collectively generate the material for this scoping study.

Literature review

Prior research focused on the development of timber thinning aim to demonstrate the latent value of the resource as a structural material in order to create a higher value resource. In focusing attention towards higher value products at all steps of the growing cycle the return to the plantation industry in general can be enhanced.

In the context of Australia's plantation industry there is an opportunity to deliver significant increases in yield during the plantation's rotation by diverting just a portion of the thinnings towards higher value products rather than just pulp and firewood. Yeates (1999) demonstrated through simple projections that the pulp market profitability would trend downwards over time as a result of increasing supply outstripping demand whereas the profitability of wood for construction would be tending upwards. At the time of the report the value of pulpwood was \$90/m3 compared to \$200/m3 for construction. If just 20% of the thinning yield were diverted towards viable construction based products then the net increase in profit from national plantations could increase by upwards of 180 million dollars (Yeates 1999). Even if only part of these projections can be realised the latent potential in the market is significant and higher yields during the life cycle of the plantation would make the industry even more attractive to growers.

Though the potential of the market can be demonstrated mathematically the current demand for roundwood structural products is limited. There are many contributing factors to the negative outlook towards structural applications but it is the general perception of roundwood and lack of technical and design guidelines that is preventing a broader understanding or appreciation of the resource (Yeates 1999, Ranta-Maunus 1999).

The challenges to be faced to create greater market acceptance include: grading the resource and the supply of consistent quality, the availability of the resource through conventional building products suppliers, the preparation of the resource to mitigate the issues of growth stresses, the treatment of the resource to enhance durability, the availability of the shelf of connector systems and finally education of designers and engineers as to the potential and good practice in design and detailing using roundwood (Yeates 1999, Ranta-Maunus 1999).

This project is looking at the use of simple delimbed and debarked unshaved thinnings. Part of the rationale of using thinnings in the round is that the embodied energy in processing the resource is quite low, almost 40% lower than processing the material into sawn lumber (TM Chrisp, J Cairns, C Gulland 2003). Processing thinning into sawn logs is problematic as the timber is juvenile and the imbalance of stresses leads to deformities and cracks in sawn boards (Yeates 1999). The yield from a sawn board is also less given the conical geometry of the logs as the greatest dimension is constrained by the smallest log diameter. The combination of log geometry and juvenile wood makes the processing of material into lumber unviable.

The use of roundwood in construction has been typically prevalent in rural or woodland setting where the resource is close at hand and in part of the local tradition. Typically buildings constructed of roundwood have been lower value assets or ancillary buildings such as shed, barns and fencing (Ranta-Maunus 1999). The folksy and traditional image of roundwood construction makes it difficult to find acceptance in more mainstream applications.

A significant aspect of creating a viable roundwood industry is consistency and predictability of the material. Though the consistency of a thinning will never be the same as a sawn log, never the less the structural capacities must be understood so that engineers can calculate structural behaviour. Visual grading and non invasive grading systems need to be developed and design tables issued in the same manner as sawn timber. The broad study of roundwood use in Europe found that there was a reliability and consistency of visual grading techniques that had a high correlation when compared to non invasive analysis and destruction testing (Ranta-Maunus 1999). These results prove that a viable system of grading of roundwood product is possible.

Connector systems are another significant issue that needs development in order for a roundwood industry to develop. There are some systems on the market though these are mainly European systems. Most systems take an embedded approach to connectors, using both steel plates and bolt or threaded rod and dowel connectors. Other systems utilise a cold formed meal nailing plate system similar to those used in softwood framing and truss systems. Both systems have difficulties in that tangential or circumference shrinkage can open large cracks in the timber making undermining the mechanical connection to the timber. Radial shrinkage can also loosen fittings over time as the overall diameter of the log decreases (Yeates 1999, Ranta-Maunus 1999). Sustainable Science.org inc has developed a sleeved connector that overcomes some of the issues associated with embedded systems. Their LPSA (light prestressed segmented arch) structural technology is a systems based approach to roundwood that can be deployed over a variety of construction types including standard houses, bridges domes and towers (Sustainable Science.Org). All systems have their place in roundwood construction though none are easily available in the general marketplace.

There have been a number of prototype structures made and reported that try and flesh out the main constraints utilising the resource. One common aspect is that though the structure and connector systems can be resolved in elegant and structurally sound ways, the irregularity of the main structure creates difficulties when attaching secondary systems and cladding. As a result many of the prototype constructions utilise a “loose fit” approach to sealing the building by using membranes or more traditional approaches such as shingles and sod roofs. The secondary systems need to be able to accommodate both the irregularity of the main structure as well as a reasonable amount of settlement over time.

Demonstration projects illustrate the aesthetic potential of the system and it is through such projects that interest in and knowledge about the roundwood is developed. A project located in Scotland for kids in need and distress (KIND) takes a Scottish timber vernacular as the inspiration for a new guest house (TM Chrisp, J Cairns, C Gulland 2003). The main structure was constructed from conifer thinnings in a triangular form which were bent on site while green. The logic of bending the main structural elements was to maximise the available internal volume and to provide an aesthetic that has been compared to a longboat of a whale carcass. The construction utilises locally available materials and skills so the constructional logic needed to be reasonably straightforward. The use of timber shingles for the A frame structure meant that there was a reasonable allowance for movement and structural irregularities. The authors of the report note that even with a new Eurocode 5 for timber construction, the system feel outside normal conventions and so needed to be prototyped and the structure tested to failure (TM Chrisp, J Cairns, C Gulland 2003). The problem therefore remains that until the number of prototypes increases and knowledge of structural performance can be codified, such structures are still found only in the domain of bespoke or specialist applications.

A series of projects in Hooke Park England takes on roundwood technology through three demonstration projects (R Burton, M Dickson, R Harris 1998). Hooke Park is a demonstration and education facility so the development of the technology has a better chance of development and knowledge dissemination. The utilisation of curved elements and organic forms in all of the Hooke Park projects is in keeping with the current spirit of the age. Contemporary architecture of the last decade is characterised through a series of signature and cultural buildings worldwide that experiment with complex form and space making. Though such complex form making is de rigueur in architectural circles it is usually created through difficult and expensive structural systems using materials with high embodied energy. The potential of using sustainable materials to create complex form as demonstrated in Hooke Park, particularly the training centre, points to a next logical step in the development of such forms.

It can be summarised that the use of roundwood both demonstrates great potential both for financial returns to growers and producers as well as great potential for innovative architectural form. The use of steam bending to generate a language of organic forms will key into the current spirit of the age. Studies have shown though that the development of technology needs to be investigated at all levels of production from the forest to the final structure. Grading, quality control and seasoning to maintain consistency are crucial to market acceptance. The development and wider availability of connection systems and design guidelines are the other aspect of the industry that needs attention in order to encourage wider acceptance and understanding of the resource. All of these aspects can be synthesised in a local context through prototype projects that test various systems and illustrate to the construction and design industries the potential outcomes. A logical extension of such prototypes would be to develop a series of prefabricated building types, demonstration projects could become more widespread and issues of engineering and quality controlled in factory settings.

Resource

The National Plantation Inventory managed by the Bureau of Rural Sciences was consulted to provide current estimates for hardwood plantation areas in Australia.
Data were divided into sawlog regime and pulpwood regime areas, to reflect the different management regimes. Assumptions for potential volumes available and suitable for structural roundwood were derived through consultation with plantation hardwood experts.

Design

Early design propositions were informed by a literature review and input from industry partners. Critical design considerations related to timber use in construction, for example durability in-ground, above ground, corrosion of fasteners, strength, stiffness, roundwood properties compared to sawn wood, and implications of untreated sapwood, were presented to the student architects. Industry inputs came from Outdoor Structures Australia, Queensland Primary Industries Fisheries and Timber Queensland in addition to the inputs from the academics coordinating the student research project.

An inquiry by design synthesised the inputs from literature and industry into a series of preliminary design propositions that worked across building type and scale. These initial design propositions were presented in a poster format for feedback from the project industry partners. Preliminary propositions attempted to present designs in the context of relevant precedent studies, potential applications and viability.

Those proposals that were deemed to have greater market potential or were better resolved were developed through large scale models and 1:1 prototype studies. These developed proposals were collated into a survey document that was distributed to industry for feedback. Financial modelling rounded out the study. Additionally, steam bending of a batch of 8-year-old plantation-grown spotted gum stems was demonstrated to students to provide an indication of the attributes, aesthetics and potential of the resource.

Survey

Representative samples from the range of preliminary design concepts produced by the UQ Architecture student group were compiled into an electronic survey document and distributed to a mailing list of over 1200 range of design professionals, relevant government departments, manufacturers and suppliers. The purpose of the survey was to ascertain the potential support for, and use of, structures fabricated from small diameter plantation hardwood rounds. To simplify the survey process for respondents, the design concepts were categorised into four groups *viz* small, medium and large structures as well as infrastructure such as sound barrier fences.

Economic analysis

An economical assessment was conducted to estimate the benefit of undertaking a detailed research and development (R&D) project on plantation hardwoods for structural roundwood.

Expected returns to the proposed research were estimated using a cost-benefit analysis approach. To account for the time preference of money (opportunity cost), future benefits and costs have been discounted to 2010 values using a real discount rate of 5%. All dollar costs and benefits are expressed in constant dollar terms and discounted to the current financial year. Investment benefits were measured using the following investment criteria:

- Net Present Value (NPV) - the difference between the present value of benefits and the present value of RD&E costs;
- Benefit-Cost Ratio (BCR) - the present value of benefits divided by the present value of the research costs; and
- Internal Rate of Return (IRR) – the discount rate at which the present value of benefits equal the present value of the costs.

Benefits “with” and “without” the project

The Benefit Cost Analysis assesses the change in benefits resulting from the project and compares it with the costs of the research. To assess these changes, two scenarios were created: benefits and costs "with" the project, and benefits and costs "without". The “without” scenario is that the project does not take place, meaning that the R&D costs would not be incurred, and the revenue associated with the new product is not received. However, it can be considered unrealistic to assume that there would be no progress relevant to the research problem in the absence of the project. Industry generated knowledge may generate some solutions to address the problem, although possibly not as promptly or effectively as this project.

New hardwood plantation area established nationally each year is forecast to continue at an average of 50,000 hectares (approximate per annum average based on the period 2004 to 2008). In the analysis this was broken down into 20,000 hectares planted to sawlog and 30,000 hectares planted to pulpwood. Initial planting density is 833 stems per hectare, which allows for mortality of 33 stems per hectare.

Sawlog plantation (20 000 hectares)

The initial planting density of the new hardwood plantations involves a high density of 833 stems per hectare, followed by thinning at year seven to 400 stems per hectare. It is assumed 25 per cent of stems from year seven will be of sufficient size and quality for straight and arched member production from each thinning. The retail price of a length of 7 metre roundwood was $28.00, with the assumption made 30 per cent of this is passed on to the grower. This equates to $8.40 per stem of roundwood at the farm gate.

The remaining 300 stems from the thinning are used in pulpwood production as this in considered to be best practice for industry. The projected farm gate price for pulp stems is $6.56 each.

Pulpwood plantation (30 000 hectares)

The initial planting density of the new hardwood plantations involves a high density of 833 stems per hectare, followed by clear felling at year seven. It is assumed only 100 stems from year seven will be of sufficient size and quality for straight and arched member production. The retail price of a length of 7m roundwood was $28.00, with the assumption made 30 per cent of this is passed on to the grower. This equates to $8.40 per stem of roundwood at the farm gate.

The remaining 700 stems from the thinning are used in pulpwood production as this in considered to be best practice for industry. The projected farm gate price for stems pulped is $6.56 each.

Thinning cost (cut and snig) per stem for either pulp production or roundwood was assumed to be $2.50.

The market will absorb all hardwood straight and arched members produced from early plantation thinning. Straight hardwood members are stronger than their softwood counterparts, and can therefore be used for structures requiring greater strength. The range of uses for hardwood straight members includes sheds, garages, bus shelters, and other light construction purposes. The hardwood arched members are a novel product that will have significant appeal to architects, landscape architects, and artists due to the ability to construct novel shaped structures with aesthetic appeal and suitable strength. Examples of the uses for hardwood arched members include bus shelters, picnic shelters, children's play equipment, and other light construction purposes.

The major parametric assumptions of the model are summarised in Table 1.

Table 1. Inputs/Assumptions for the Cost Benefit Analysis

Inputs/Assumptions	
Sawlog hectares planted per year (Qld, NT, NSW)	20000
Pulpwood hectares planted per year	30000
Initial planting density (stems/ha)	800
Number of stems per hectare from year 7 thin	400
Yield per hectare (cubic metres)	175
Price per cubic metre	$30.00
Price per stem (for pulp) farm gate	$6.56
Thinning cost per stem at year 7	$2.50
Percentage of stems per hectare from year 7 thin suitable for roundwood	25%
Number of stems per hectare from year 7 thin suitable for roundwood	100
Retail price per linear metre of roundwood	$4.00
Length of roundwood stems (metres)	7
Retail price per roundwood stem	$28.00
Price per stem (for roundwood) farm gate	$8.40
Research costs - year 1	-$284,000.00
Research costs - year 2	-$188,000.00
Discount rate	5%

The cost benefit analysis focuses on benefits received privately as a result of new higher valued markets for timber which previously had no value. It must be noted that there may be further benefits associated with the additional value adding processes, but these have not been accounted for in this analysis.

Results and discussion

Within the terms of reference of this pre-study, the results gained from the design inquiry demonstrated that there was a broad application of steam bent thinnings through a variety of building types. At the same time though the process of critically evaluating the designs opened more questions that could not be sufficiently resolved within the pre-study's scope.

Initial design concepts

Initial design ideas and possibilities were generated during a full group brainstorming session. Through discussion it was decided that the range of possible solutions would be best packaged into four defined project types based around scale and use. In simple terms the categories established were as follows:

- Small sized buildings / structures
- Medium sized buildings / structures
- Large sized buildings / structures
- Infrastructure projects, systems and structures.

Within the group each student decided to take on a design within one of the broad project categories so that there was an even spread of designs across categories. These initial concepts are presented in Appendix 3.

During the critical review of these initial schemes a number of common themes emerged. First and foremost the initial designs tended to be quite narrowly focused though in discussing the possible applications it was found that many of the proposals could be adapted to other more general applications. It was found that in order to be viable, design prototypes needed to be sufficiently *generic* so for example a shade structure could become a bus stop which in turn could become a sport stadium.

The *scale* of the design elements was also highlighted as an issue. Small structures such as a bus shelter may be difficult to execute given the scale of the structural elements. Sometimes direct adaptation of a structure type would not work as they would sit outside the bounds of the materials "natural" design and structural properties. There was a view that the material "wanted" to be made into some structures but could not be adapted to others.

Some of the medium scaled structures seemed very well suited to the resource. The clear span of a single log made it appropriate to residential and residentially scaled structures. The clear spanning potential meant that a generic structure could be fitted out in a number of different ways, making it flexible and adaptable. Particularly for houses there was a focus on the speed of erection to stand up the frame which would lend itself both to self build or self finish. This aspect of self build and off grid or remote area housing became an important aspect. Discussions of regional housing options, indigenous housing were discussed, mainly as a way to promote the sustainability of the resources as well as the potential for community engagement and employment opportunities for regional and remote communities.

Many of the schemes utilised the structural elements vertically. The "Umbrella Structure", "Gunyah" and "Woodland Hideaway" (refer Appendices 3.2, 3.3 and 3.6) utilised the elements vertically and integrated in the roof structure. There is a tendency for the elements to be used in similar gridshell or "A" frame type configuration in the students' proposals as well as in many of the examples uncovered in the literature. Perhaps the reasoning is that used vertically, the stems are in a configuration closer to the way they are nature and aesthetically seem to be in character with the material.

The propensity towards "integration" of vertical structural elements points to another trend which was a strong emphasis towards organic forms and a green architecture. For some the issue may be that the folksy aesthetic lends itself only to niche applications however through discussions we believed that a green agenda and returning to nature was becoming more entrenched in mainstream attitudes to the built environment. In the short to medium term though it was felt that it would be easier to market a small to medium scale structure in park like settings and in circumstances where the object was integrated more tightly with a natural environment. This perhaps precludes suburban and urban applications however there are instances in the public realm such as school, sporting facilities and public parks where such structures would find many applications.

Many of the larger scale buildings tended to focus on simple linear shed like buildings. Variations of the portal frame or "Nissen" Hut were the dominant themes explored. Though for most the aim was to create a storage or industrial facility, it became evident that uses such as shade over parking, agricultural applications and community and school sports halls would be a more appropriate fit.

Issues of the consistency of the material became issues when the stems were configured into longer span elemental structures. Most of the student's schemes made assumptions about the level of variability of the resource with most thinking that the material would be quite consistent and lend itself to prefabrication. When the group started working with full scale elements, this assumption was dismissed and many adapted their ideas to account for the material's variability.

The steam bending of stems lent themselves to some quite elegant curvilinear forms. Similar forms in materials such as steel would require the use of circular hollow sections which would be at a greater expense both in terms of dollar value and value in carbon. One of the proposals looked at an arched structure that utilised the same bending geometry for all elements so that the manufacturing process is streamlined as well as enabling the structure to be scaled up and down (refer Appendix 3.11). The issue with this approach though was that the conical stem geometry was difficult to resolve due to the differences in stem size and geometry. A universal elemental system would require that the logs be shaved. In practice this would not be viable with thinnings which were intended to span over great distances. The resolution would need to come with the design to ensure that the geometry of the structures were cognisant of the effects of the variable stem geometry and diameter.

Particularly for the larger scaled designs, the ways and means of joining elements became a major issue. There was not a chance to devise 1:1 prototype connectors within the scope of the project so literature research was the main source of solutions. Simple scarf joints with large elements were deemed to be aesthetically unacceptable for anything other than an agricultural building. A variety of large scale biscuit joints and joining plates were used. One solution that was used in a number of schemes was a pipe connector in the end of the log. There is quite a variety of design options with this solution to both join logs to one another in a three dimensional structure as well as connecting to footing structures. Future studies would benefit from a closer investigation of the pipe connector and prototype connectors made.

Some students became preoccupied with the jointing systems as the main focus of their design. The "Universal Roundwood Connector System" (Appendix 3.13) took on the position that smaller straight shaved logs provide more flexibility as a system. Though this position strayed a little from the overall approach of the research project the connector, based on a Dutch prototype, is simple and would allow a variety of structures to be devised from a simple kit of parts. The problem though with the scheme was that it assumed a rectilinear approach to structures and did not have the same aesthetic appeal as the more organically formed structures.

Two propositions looked at the application of roundwood thinning as infrastructure elements. Both schemes (see Appendices 3.12 and 3.14) focused on barrier systems, one for roadside barriers and the other for wind breaks to be used in agriculture and remote communities. The beauty of either of these systems is that there is potentially a large demand for the product and that the existing in ground treatments used for power transmission poles can be utilised.

The "Curvuer" roadside noise barrier system (Appendix 3.12) is especially interesting for two reasons. Firstly the aesthetic appeal of the overall system is in a different league to traditional barrier systems. Traditional barrier systems rely on surface treatment alone as the primary aesthetic component where as the “Curvuer” system looks at surface and form. The overall aesthetic effect is almost like land art with the organic forms more in keeping with the natural environment and the natural flow and curves of the motorway. The issue of cladding such an irregular system is perhaps not as problematic today with the commercial availability of large scale scanning and CNC cutting of plywood sheets. Other than the aesthetic appeal, the curved form may assist in deflecting the sound away from residential areas, reflecting sound over adjacent houses and reflecting it back into the source.

Though the range of student projects was promising there were still some applications that remain unexplored that have significant potential. Children’s play structures and shade structures, bridges and towers were not investigated in any of the proposals. In addition there was a focus on the design of the overall form and structure so little investigation into the possible treatments, weathering and footing conditions. It was accepted that these were outside the time frame of this pilot study.

Developed design concepts

Initial designs yielded a good breadth of solutions that were developed though large scale model making and working with the material at a scale of 1:1. Detailed model making provided some insights to the nature of timber and thinking through the process of bending. It also brought the importance of the connection and the balance of structural elements into sharp focus. Given that many of the schemes worked with organic wall and roof forms, the method of cladding over a complex surface also became a major part of the focus.

Not all of the initial designs were developed. Some schemes were rejected and others were conflated into a new proposition. The scale of investigation ranged from 1:50 up to 1:10. There was a scheme developed in each of the categories that were defined at the start of the project.

The material used to simulate the roundwood material was Tasmanian oak (*Eucalyptus* spp.) dowels. Though the material was a consistent diameter and did not have any surface imperfections, it was best in the circumstance as using smaller tree limbs in the experiment did not work as these stems were too irregular.

The dowels were pre soaked for at least two days and were steamed in an autoclave or simply boiled for 10 minutes. Both options had equal effect. Bending rigs were made to set the dowels into bent geometries. The jigs were set to 20% over the required curvature to account for the spring back effect. It was found during the testing that the amount of spring back was consistent at around 20% and that this was in accordance with the anticipated spring back of the actual thinning.


Plate 1: Model bending rigs


Plate 2: Steamed dowels being set in rigs

There were a significant percentage of failures in the dowels during the bending. Many snapped and some that didn’t had significant compression failure. On average about 20% of the dowels snapped or had compression failures. The explanation for the percentage of failure could be accounted in some instances due to the variability of the grain in the dowel. Given that they were a dressed product and from different parts of the tree, some dowels had a greater propensity to splitting. It was found that the dowels had a “natural” way to bend and there was a skill in bending the dowels as per the way it wanted to bend. Though this was an issue during the model making phase we felt that this effect would not be replicated in the 1:1 tests.

Two aspects that were of significance though that would transfer between the model and 1:1 production were the effect of the bending jig set out points and the speed with which the stems were placed in the bending jig. The set out points of the bending jig could significantly affect the way propensity for compression failure. The speed with which the dowels lost heat in the time they were placed in the jig significantly affected the success rate of bending. We were all surprised how quickly the capacity for bending diminished even with small changes in temperature.

The difficulties in cladding an irregular structure were revealed both in the model making phase and subsequent 1:1 prototyping studies. There inevitably needed to be a level of adjustability of the fixing between the primary structure of thinning and the secondary structure of sawn or machined material. Structures that utilised fabric or other tensile membranes would inevitably be more adaptable to a bent thinning structure. Therefore building types such as shade pavilions, play structures or simple infrastructure where weather tightness was not an issue would be easier of work with. This is not to say clad buildings are not appropriate to the technology, only that account needs to be made for the tolerances and perhaps a greater level of skill needed to clad such structures.

1:1 prototypes and material studies

Students participating in the pilot study worked with the material through all scales including 1;1 studies. The importance of the engagement with all scales of the material is critical as the hands on experience feeds back into the tacit understanding of the material during the design phase. Though done at the end of the research cycle, the reflections on the experience through all phases of the research project were invaluable.

A pre-designed structure utilizing hardwood thinnings was presented to the group to assess. The design of a “Park Pod” (refer Appendix 5) was developed by the student’s coordinator, Michael Dickson. Though the prototype was not completed during the project phase, cladding studies at 1:1 were completed.

Plate 3: Cladding studies for park pod

Plate 4: Cladding studies for park pod

The park pod design is based on a simple circular geometry using the stems in a vertical configuration. The pod can be scaled to perform as a simple shelter all the way to a small bush cabin. The specific aim of the design was to create a cladding challenge hence the structure was presented to students as a structure only with no development of secondary systems to support cladding.

Three bays of the park pod were constructed for students to experiment with. The option of cladding directly to the stems was dismissed as the irregular profiles created too many difficulties. Experiments in weaving flexible material were undertaken and though this was more successful it resulted in irregular and three-way bending of sheet material and required a significant amount of skill in the application.

On reflection of the experience a system of horizontal girts constructed from plywood was decided so that the outer circumference of the ply could be controlled and the inside circumference be adjustable through cutting and trimming.

Bending demonstration

A final aspect of the experiments involved the bending of full sized stems. Thinnings were harvested from an 8-year-old spotted gum sawlog plantation located near Amamoor in south-east Queensland. The stems were selected based on standard thinning rationale to improve the spacing in the plantation. That is stems were removed if they were competing with a superior, dominant neighbouring tree. The range of stem diameters at breast height over bark (DBHOB) was 10 cm to 15 cm. The harvested stems were delimbed, debarked and merchandised to standard lengths of 6 m for transportation.

Plate 5. 8-year-old spotted gum roundwood stems.

Upon delivery to DEEDI's Salisbury Research Centre in Brisbane, the stems were docked to 4 m lengths and received processing treatments to minimise end splitting then placed in a water tank to maintain their green condition. End-split treatments included ring grooving with a hole saw and with longitudinal external kerfing with a circular saw.

Prior to bending the stems were held in a steaming chamber for approximately 24 hours under wet steam conditions of 90°C to 100°C and 100% relative humidity (RH%). Stems were removed from the steam chamber individually and placed in the bending form within 5 minutes, then the tip (small end of the log) was pulled around the form with a forklift and tied off.

As with the experiments during the model phase, it was found that the stems lost heat quickly in the time they left the kiln and were set on the bending rig. Though the bending of the stems did not result in the same percentage of failure, the effect of cooling during the bending process was noticeable. The importance of the proximity between the steaming and the setting in the bending rigs is a major consideration for any future production facility and ideally would form part of future research projects.

The bent stems were covered with a tarpaulin for weather protection during the setting period of 3 weeks.

Plate 6. Steamed logs fixed onto the bending form. Note the ring groove and external kerf treatment used to limit end splitting.

Plate 7. Retained curvature 7 days after release from the bending form.

Survey

The survey prepared by Timber Queensland (TQ) was located on a platform by their external Information Technology resources and emailed to a database of over 1200 people across the eastern states of Australia. The content of the Survey Questionnaire is provided in Appendix 1.

Response

There was a response rate of approximately 5%. Although only a small proportion of those emailed responded to the questionnaire, the 62 people that did represented a broad cross section of designers, specifiers, users and infrastructure owners/managers.

Figure 1 provides a breakdown of the respondents by category. The 'other' category included builders, a veterinarian and sales and marketing. The 'architect' category includes landscape architects.

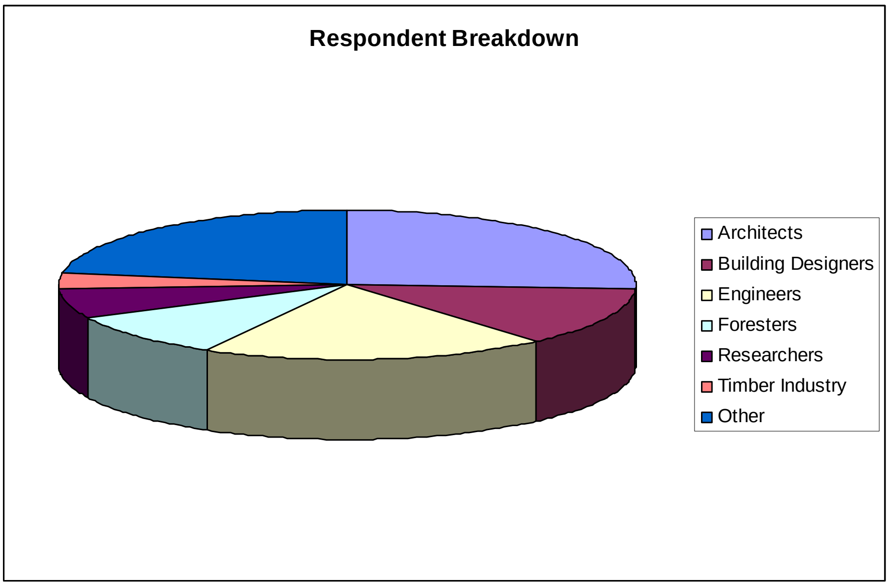

Figure 1. Breakdown of respondents by occupation.

Feedback

In addition to the simple questions in the survey, respondents provided extensive written comments, personal impressions and questions which provide an insight into the concerns and needs of potential designers and users of the material. This valuable feedback is are listed under the relevant survey question in Appendix 2.

For the survey question "Your overall impression of the designs and concepts was…?" 54 respondents or 87 % liked the designs, 8 (13%) neither liked nor disliked, and no respondents disliked the designs as illustrated in figure 2.

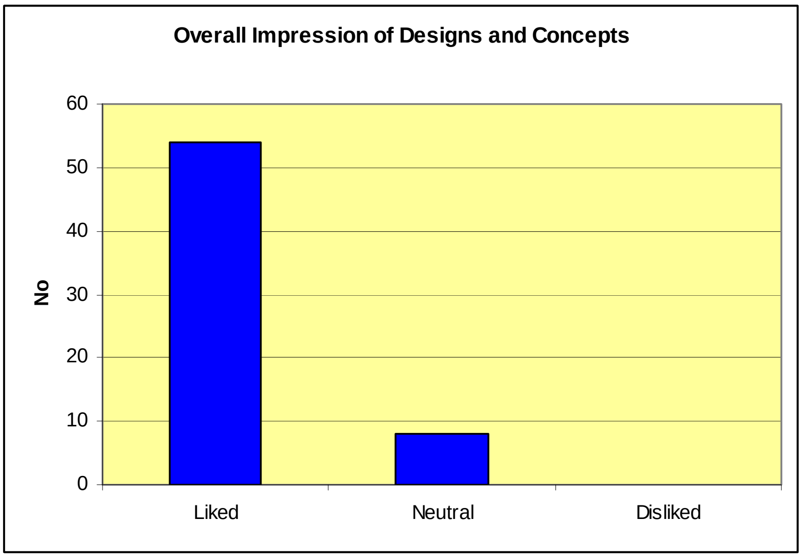

Figure 2. Overall impressions of the designs and concepts (number of responses per 62)

Some recurring feedback responses mentioned the innovative and attractive designs and the potential of curved designs. Another recurring positive comment was that the concepts were not “boxy”. The respondents noted that it would be important to make designers and other users aware that the roundwood stems are not regular cylinders and tending to conical in shape. The respondents requested further information on the structural properties of roundwood.

Respondents were asked to rank the general appeal of each concept group (that is: small, medium, large and infrastructure) from 1 highly appealing to 5 forget it. When the results for the two positive scores (highly appealing and appealing) are combined, it can be seen that for each case the majority of respondents found the designs appealing. The rankings for each structure category are presented in figure 3.

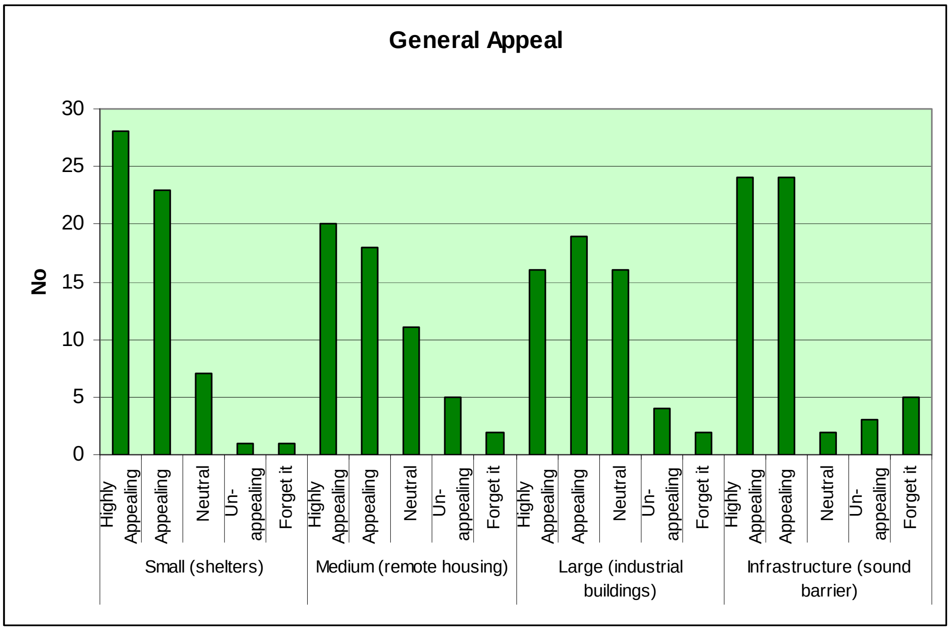

Figure 3. Respondents’ ranking of general appeal of design concepts (n=62).

The trend for positive responses to the concepts was further highlighted by data returned for the survey task “For each of the design concepts, please rank their potential for market uptake/commercialisation (1) high (2) medium (3) neutral (4) low (5) very low”. Respondents suggested that prefabricated building kits could provide a commercial solution for more affordable structures. Questions raised by respondents were centred around technical aspects such as durability, finishing, maintenance and lifespan.

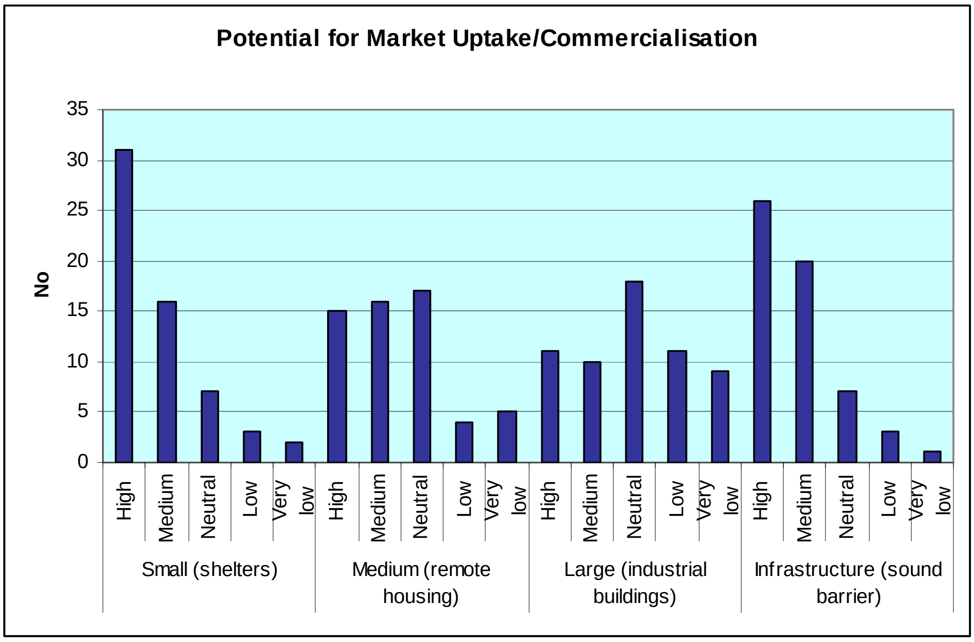

Figure 4. Ranking of the potential for market uptake/ commercialisation (n=62).

When asked whether they considered that detailed R&D towards commercial realisation was justified or warranted, almost all respondents (60 out of 62) said that they support or fully support a project, compared to 2 who were neutral on the point. No respondents suggested that they didn't support R&D on the topic. The development of readily available standard and efficient jointing systems was a common theme in the responses, highlighting the need for this aspect to be covered in future R&D efforts.

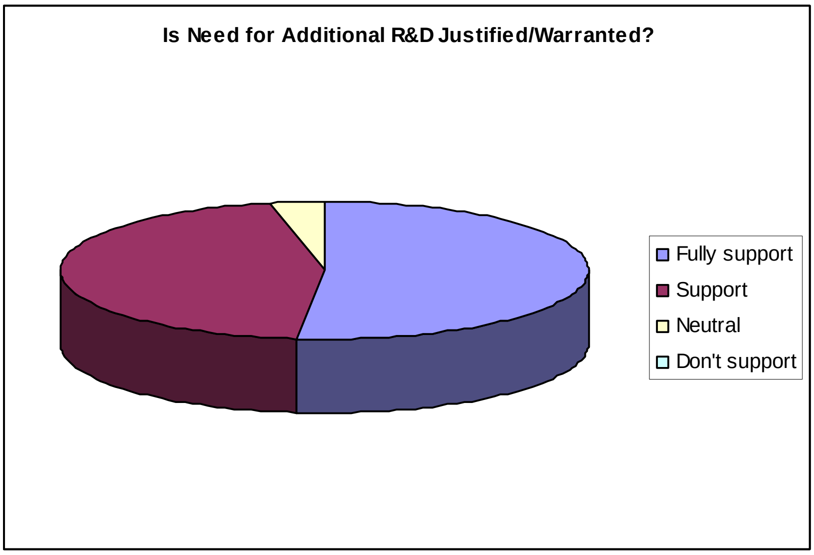

Figure 5. Views of respondents on further R&D on structural roundwood.

In the opinion of the respondents, the main constraints to commercialisation were confidence in durability and lack of suitably priced and available connector systems for rapid construction.

One of the survey questions left unanswered by most respondents was where they were asked to provide an estimate of the potential market size and annual expenditure on the types of structures represented by the conceptual designs. Twenty-eight people provided data for an estimated annual spend (Figure 6) and only twenty-one of the 62 respondents were able to estimate how much material might be used annually (Figure 7).

The breakdown of responses per the four structure categories appear in Table 2.

Table 2. Number of responses regarding potential markets.

Concept category	Number of responses	
	$/annum	Area or lineal m/annum
Small	16	12
Medium	4	3
Large	3	2
Infrastructure	5	4

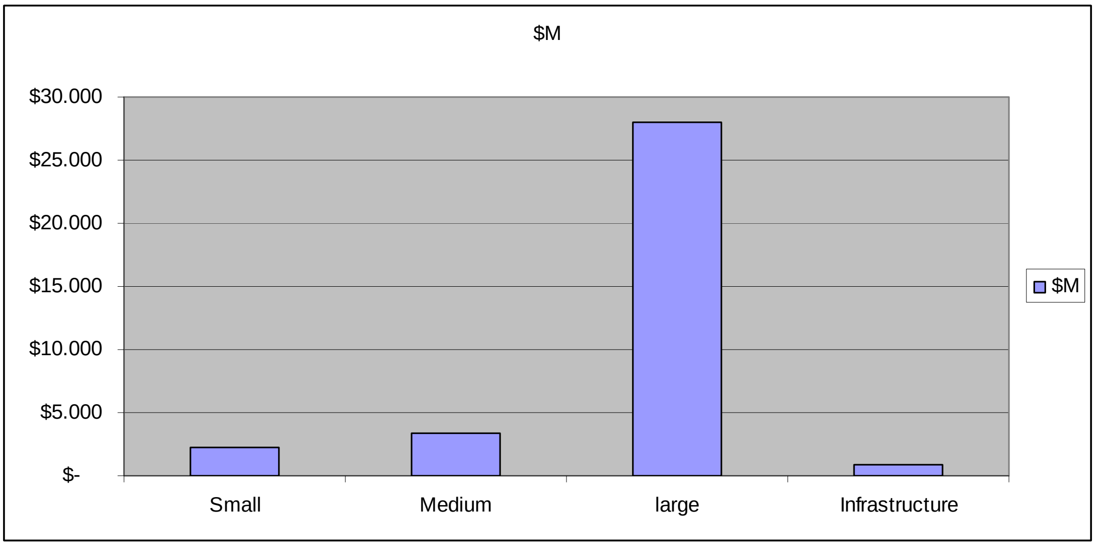

Figure 6. Estimated annual spend on roundwood structures ($million, 28 responses).

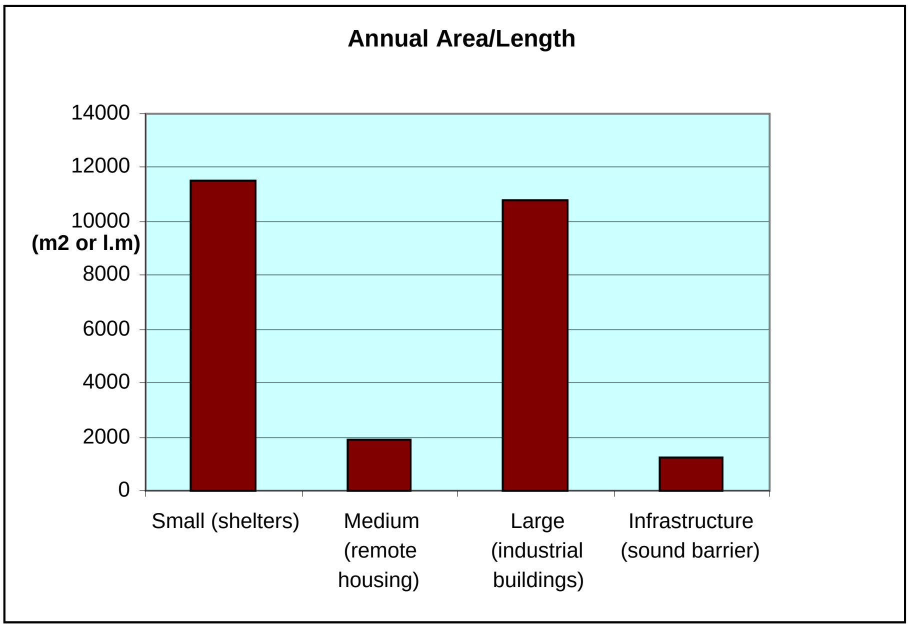

Figure 7. Accumulated size of structures per category per annum (21 respondents).

Economic analysis

The financial benefit cost analysis indicates reasonable expected returns to the proposed project. Using the 5 per cent discount rate:

- internal rate of return (IRR) 492%
- benefit cost ratio (BCR) 223:1
- net present value (NPV) $100.3 million.

Sensitivity analysis

Sensitivity analysis has been undertaken on the key variables, the discount rate and the retail price received for 7-year-old stems sawlog plantation thinnings or pulp logs) for roundwood. The results for this analysis are presented in Table 3.

Table 3. Sensitivity analysis

	Discount rate			Roundwood price reduction		
	5%	8%	10% -1	0% -2	0%	-30%
NPV ($m)	$100.3 $7	5.2	$63.1 $5	4.2	$8.2	-$37.9
BCR	223.2 1	69.1	142.0 1	21.2	19.1	-82.9
IRR	492% 49	2%	492% 34	4% 10	3%	

Discussion

The base-case results and sensitivity analysis indicate that a detailed R&D project *Production of higher value products from plantation-grown hardwoods originally established and managed for pulp production: roundwood structural products* project has significant benefits and presents high return to the project expenses.

Table 3 shows that the net present value of the project costs and benefits is high. The net present value decreases significantly when there is a projected price reduction of roundwood, becoming negative if the projected price received for roundwood timber declines by 30 per cent.

Production of arched and straight light structural members is expected to increase the viability of the hardwood plantations through utilisation of the early thinning timber volume. It must be noted that this analysis was not based on past or current figures, but forecast values.

Conclusions

This project combined interdisciplinary expertise including scientists, engineers, architects, a processor/manufacturer and economic analysts to consider opportunities for commercial uses for small roundwood hardwood products. Interestingly this skills' mix provided the forum for lateral thinking and development of concepts. Scientists and engineers bring ideas to process and assemble materials, the architects expanded on this to explore a range of designs across different scales of construction. The processor/manufacturer maintained a commercial and realistic market potential outlook for the designs and the respondents to the survey provided essential feedback to inform further research.

Despite only 5% of recipients (62) of the survey responding to the questionnaire, important data and information have been obtained to guide future research and development on plantation roundwood structures.

The results from this survey clearly indicate a high level of support for further development and commercialization of the concepts and uses for small diameter round hardwood plantation timber and as well as the necessary R&D to bring this to fruition including:-

- durability
- lifespan
- connections
- structural properties data

- cost
- approvals and compliance with Timber Structures Code and Building Code of Australia
- finishing and maintenance

The economical base-case results and sensitivity analysis indicate that a detailed R&D project has significant benefits and presents high return to the project expenses.

Despite the small scale of this pre-study, the results indicate that it has been a valuable and efficient process to evaluate the need and also the scope for a detailed R&D project. The mix of competencies involved in the pre-study proved to be a productive melting pot, working synergistically towards the development of a future collaborative project.

Recommendations

The detailed R&D project "*Production of higher value products from plantation-grown hardwoods originally established and managed for pulp production: roundwood structural products*" submitted to FWPA in February 2009 should be reconsidered with a greater emphasis on:

- Develop and refine a post harvest treatment: end coring and longitudinal kerfing
- Propose a grading system
- Characterise of minimum acceptable stem geometries
- Resolve durability/weathering/fire performances issues
- Design primary fixing and fastening systems
- Design secondary fixing (panelling, cladding, roofing etc.)
- Design and construct demonstration buildings and noise barrier
- Propose a prefabricated system
- Assess current building code and standards application (technical and design procedures)

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Acknowledgements
For their time, effort and enthusiasm for this project, the assistance and participation of the following people is gratefully acknowledged:

DEEDI
Adam Redman, Eric Littee and Dan Field, in assisting with the bending trials.
John Huth Rob McGavin
Org

UQ Architecture:
PhD Candidate: Tim O'Rourke
Workshop Assistants: George Dick, Matt Dixon
Students: Andrew Carter, Claire Chippendale, Daniel Cocker, Will Downes, Sean Gill, Will Gray, Karl Ho, Mathieu Levesque, Michael Lineburg, Kerry Martin, Brihony McKauge, Anya Meng, Lasan Nguyen, Jeremy Slater, Nicholas Vella.

Outdoor Structures Australia:
Ted Stubbersfield

Forestry Plantations Queensland

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