Residential Timber Construction - Evaluating Emerging Technologies

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ABSTRACT

Timber has always had a profound role in residential construction; in Australia it has been mainly used for flooring and stick framing erected according to long established recipes. While the local industry has recently embraced some new technologies such as Laminated Veneer Lumber, other more innovative ways of building with timber now gaining acceptance overseas, are not being adopted locally. This document describes a systematic process undertaken for the purpose of evaluating the suitability of overseas and local emerging timber technologies (ETs) for use in the Australian residential construction industry. The purpose of this was to help the local industry set its technology development agenda. To assess the local suitability of the Emerging Technologies, a modified Delphi process was employed to interrogate the experience of a varied group of specialists each of whom had relevant expertise in the construction industry. The process aimed to arrive at a consensual ranking of emerging technologies against a variety of criteria for publication in a web database. The website has been made available to encourage and assist industry in taking up ETs in Australia.

Keywords: emerging technologies, timber, Delphi method.

INTRODUCTION

Residential construction is one of Australia's largest industries and one of its biggest employers. Timber framing has been in the past (and still remains) one of the main areas of residential construction. Advances in material technology, construction processes and structural design have led to the emergence of new ways of using timber for residential construction - the decision making process is often driven by timber's environmental credentials. Many Emerging Technologies (ETs) in timber that are gaining acceptance in overseas markets (such as the "Leno" cross laminated panel system and the "Lignotrend" built-up box girder system) are yet to appear in Australia. A study by Phillip Paevere and

Colin McKenzie (2006) identified 88 emerging timber technologies that may be useful to the Australian industry. In a 2011 strategic investment plan for Forest and Wood Products Australia (Mitchell and Tucker, 2011) - aimed at increasing the use of wood products in residential construction - "innovation and technology" were identified as key areas of interest. Consistent with this, Forest and Wood Products Australia requested the authors to undertake an updated study of emerging technologies.

With a few notable exceptions, Australian timber industry players have in the past, largely confined themselves to the residential construction sector. Overseas however, new developments in timber technology are seeing timber used in larger-scale structures such as high-density housing and public buildings. This work aims to make the local timber industry aware of the new technologies and to provide guidance on their possible adoption with a view to the opening up of new markets for Australian timber. This project revisits Paevere and McKenzie's 88 ET's of 2006, discards those which were not seen as having potential and explores other emerging technologies which appear to be gaining acceptance elsewhere.

The identification and evaluation of ETs is necessarily a subjective process. This work employs the "Delphi" method to distill from the subjective opinions of a group of experts, a meaningful evaluation of each ET's degree of local suitability in terms of project cost, time, quality, sustainability, life cycle, market suitability and end user benefits.

The Emerging Technologies that were assessed as having potential are described in a web database (http://buildinginnovations.fwpa.com.au/).

RESEARCH METHOD

Overview

Emerging technologies in timber were sourced from around the world with the help of a network of interested people. Overseas contributors also checked that the essential aspects of their technologies had been covered. The process of identifying emerging timber technologies and evaluating them for local suitability needed to be undertaken with procedural rigour. To this end, the project adopted the "Delphi" method to revisit some of the ETs examined by Paevare and McKenzie plus other, newer ETs identified since 2007.

Overview of the Delphi method

The Delphi method is a systematic process which is used to distill the subjective opinions of a group of experts into a consensual group outcome (Keeney, 2011). The method aims to overcome the perceived shortcomings of decisions made by the meetings of a committee. Although necessarily subjective, the resulting oracular pronouncement of a Delphi group is considered to have greater validity than each of the contributing individual opinions. Stitt-Gohdes and Crews (2004) state that the Delphi technique originally emerged at America's Rand Corporation in the early 1950s where it was used to enable a group of experts to arrive at forecasts for the US military. The method has been seen to be effective in medical decision-making where there is some urgency for the opinions of a group of specialists to be resolved in order to arrive at a consensual patient care procedure (Keeney et al, 2001 and 2011). Consensus has been defined in a variety of ways; the aggregate judgments of respondents (Delbecq1975), the meeting of a predetermined consensus level within a scoring system (Williams and Webb, 1994), the central tendency of scoring (Dajani et al, 1979), or the reaching of a consistency of response across successive rounds (Dajani et al 1979).

Adler and Ziglio (1996) see the Delphi method as an iterative process of communication contrived to produce a detailed examination of a topic - not one that forces a quick compromise.
Authors such as Lynn et al (1990) describe key pre-requisites for a classical Delphi data gathering technique:

- Anonymity of responders; this prevents the status or personality of one or more panel members from dominating the discussion, frees participants from personal biases and discourages the "bandwagon effect".
- Structured information flow; experts make their contributions via questionnaires which are processed by a moderator to remove irrelevancies and formulate feedback.
- Feedback; the participants are shown the distribution and direction of the group's responses and invited to refine their previous inputs in the light of the group direction.
- Role of the Moderator: the essential co-coordinator of a Delphi group (Rowe et al, 2005) facilitates and co-ordinates the working of the panel, filters the responses and formulates the feedback in the light of conflicting and or common viewpoints with a view to reaching a consensual group perspective that would be otherwise unobtainable.

There are four phases in the Delphi process. The first explores the subject being researched, giving participants the opportunity to contribute information they feel is appropriate. The second phase moves to determine an understanding of how the entire group views the issue. If significant disagreement is determined, the third phase is used to explore that disagreement and determine reasons for differences. The fourth phase is a final evaluation of all gathered information" (Linstone & Turoff, 1975 cited by Stitt-Gohdes and Crews, 2004).

The experts of the assessment group can be operationally defined as "informed individuals" (McKenna, 1994), "specialists in their fields" (Goodman, 1987) or "highly knowledgeable in specific subject areas" (Davidson,1997; Adler & Ziglio, 1996). Green et al. (1999) point out that selection of an appropriate panel dictates the underlying validity of eventual outcomes of the process. Key requirements for a Delphi expert put forward by Adler and Ziglio (1996) include; relevant knowledge and experience, the capacity and willingness to participate and effective communication skills. In this context, it is worthwhile pointing out that individual traits such as knowledge alone do not necessarily imply expert status as there may be a vested interest or emotive issue relating to the item under discussion. It is important that an expert remains impartial and provides input that reflects current practice.

Application of the Delphi Method

The classical Delphi method was typically undertaken between remote participants using questionnaires and the postal system (Keeney et al 2006). Variants of the classical approach have emerged with technological improvement over time. One such variant is the "real time" approach whereby experts are in the same room and consensus is reached in real time rather than by post (Keeney et al, 2011, Eggers and Jones, 1998). For this work's evaluation of emerging technologies in timber, a modified "Real Time" variant of the Delphi method was employed. It used expert workshops and a scoring instrument (see appendix) together with a dedicated web database to facilitate the uploading and exchange of information between panel members. A description of each ET was uploaded onto the database along with perceived benefits and limitations.

The overall research process is defined in greater detail below:

- Development of the ET evaluation instrument: A model instrument was issued and modified according to feedback from the group. The final version included the ability to give an overall Likert scale perception score for each ET, plus scores for six individual criteria (refer Appendix for details). In addition, there was mechanism for identifying key "pluses" and "minuses" active in each criteria together with brief qualitative comments. The instrument was pilot tested to ensure clarity and understanding.
- Filtering to remove untenable ETs from the Paevere and McKenzie report: Several of the originally evaluated ETs that received a low score of less than 5 out of 10 were unlikely to be useful in the ongoing study and were screened out. Also removed were ETs for which there was no longer a dedicated web description, those that

did not have a clear ongoing relevance to timber construction, those that were unlikely to be cost/time/quality competitive, those that were no longer an "emerging" technology and those that showed no measurable performance improvement over existing methods.
- First expert Workshop: this focused on the review and evaluation of the retained technologies from the Paevere and MacKenzie report. Each ET was presented to the group on a large screen. The presentation was followed by open discussion and debate. Each member then used the scoring instrument to evaluate technology before submitting it to the workshop coordinator.
- Sourcing of new ETs for the second workshop: This was undertaken via the expert panel's extended network of contacts in Europe, the United Kingdom, North America, Japan and New Zealand. The contacts' credentials were screened by relevant panel members. The international contacts were given access to the web database for checking and uploading information. Additional ETs were sourced from overseas timber associations and the proceedings of timber related conferences. Ultimately, 38 newly identified technologies were uploaded onto the database for evaluation in the second workshop.
- Second expert Workshop: The newly identified technologies were evaluated using the same process as that of the first workshop.

In the workshop sessions a chairman/moderator ensured that no one expert's opinions was seen to dominate those of others. The chairman's other key role was to re-express and summarise the individual responses during discussions and facilitate consensus by providing feedback and suggesting compromise where appropriate.

Following the workshops, scores were aggregated and averaged. ETs scoring more than one standard deviation below the overall average were rejected.

As a result of the second workshop, 21 of the 41 ETs identified in the first workshop were retained for inclusion in the final data base of worthwhile ETs and 25 of the 38 new ETs from the second workshop were retained (giving a total of 46). At various times up to eight experts assisted; each had either relevant post graduate qualifications and/or at least 10years senior level experience in one or more of the following fields: construction management and process, material science, design, structural engineering, sustainability, timber marketing.

A review of the scores was undertaken with a view to improving consensus; where considerable variance occurred, experts were asked to review their scores or offer conditional statements describing their process of scoring. The experts were then invited to review the final database online.

RESULTS

Overview

Emerging Technologies were broadly classified into the categories and subcategories shown in Table 1 below. Less than half of the ETs examined by Paevare and McKenzie in 2006 were retained for review in the first workshop whose results are shown in Table 2. Table 3 presents the ETs examined in the second workshop and their scores.

Since the 2006 work, there has been a growing adoption of engineered timbers in the local industry with a resulting increased confidence in those materials' structural behaviour. It is also apparent that structural system has a tendency to provide the underpinning logic (or driver) that determines the rest of the construction system used in a building – hence it tends to dominate higher level decision making. Consequently, construction systems utilising engineered timber formed a clear majority of the emerging technologies identified as possibilities for the Australian timber industry.

Table 1: Emerging Technology Classification.

Category	frequency (%)	Sub-category	frequency (%)
Construction systems	24 (52%)	• Floor, roof and wall systems • Fire sound and thermal insulation systems	20 (39%) 4 (8%)
Componentry & materials technology	16 (35%)	• Engineered & composite materials • Companion materials • Connectors & Fitments • Improved Wood • Timber cladding, linings &flooring	1 (2%) 1 (2%) 5 (12%) 8 (14%) 1 (2%)
Integrated Design & Delivery Systems	6 (13%)	• Building information modeling • Supply chain management • Design for manufacture	2 (4%) 2 (4%) 2 (4%)
Totals:	46		

Table 2: Evaluation of Previously identified ETs, Workshop 1

Main Category	sub-category	ET Name	Description	Origin	Score
Construction Systems	Floor/ wall/ roof systems	"Lignotrend" timber system	Massive wall/floor panelised timber system	Europe	7.6
		Massive Timber "die Brettstapelbauweise"	Massive wall/floor panelised timber system	Europe	5.5
		"Leno" massive timber system	Massive wall/floor panelised timber system	Europe	8.1
		"Lignature" floor system	Massive wall/floor panelised timber system	Europe	8.0
		Structural insulated Panel System (SIPS)	Expanded polystyrene foam & timber sandwich panel	USA	6.9
		Carter, Holt, Harvey; panelised building system	Prefabricated wall frame with ply sheathing/bracing	Australia	6.8
		Hinged Roof	Prefabricated gable roof panels	Europe	5.0
		Sodra Smart	Manufactured timber stud system	Europe	6.5
		MHM Solid wood	Massive timber wall/floor units. Layered planks connected by aluminium spikes.	Europe	8.0
	Fire/ sound /thermal insulation	The Soundbar System	Acoustic separation floor system using I-joists, special sheeting with a Gyvlon screed	Europe	7.6
Materials technology & Componentry	Companion materials	Mortarless brick veneer/ "Novabrick"	Exterior wall system using specially shaped masonry units (75 or 100mm). No mortar required.	USA	7.0
	Connectors and Fitments	Simpson strong tie shear wall system	Shear wall bracing panel and fitment system for design with large openings and short wall runs	United States	7.0
		Plastic composite nails – Raptor nails	Plastic composite nails that can be substituted for traditional metal nails in non-structural applications.	United States	4.5
		Abuild	Steel angle reinforcing of timber to increase the span of timber beams.	New Zealand	6.9

Table 2: Evaluation of Previously identified ETs, Workshop 1 (continued)

Main Category	sub-category	ET Name	Description	Origin	Score
Materials technology & Componentry	Improved wood	Titanwood (Accoya)	Acetylisation treatment of wood to improve dimensional stability and durability	United Kingdom	6.1
		Thermowood	Thermally modified wood providing improved durability, dimensional stability and insulating abilities.	Europe	5.9
		Kebony	Furfurylation treatment of wood to improve dimensional stability and durability	Europe	
Materials technology& componentry	Improved wood	Woodheart	Utilises the pine heartwood content in all the externally exposed surfaces of windows and door sections where high stability and durability are needed.	Europe	7.6
		Greenweld	Gluing process that joins pieces of sawn timber while still green (i.e. before drying and planing) thus reducing timber manufacturing processes.	New Zealand	6.6
Integrated design & delivery Concepts	Design for manufacture	Integrated interior infill – House chassis	Design concept that separates the structure and fit out then utilises furniture and cabinetry as fit out	United States	6.5
		Modular housing	Integrated design and delivery system for manufactured housing	Various	

Table 3: Newly Identified ETs, Workshop 2 evaluations.

Main Category	sub-category	ET Name	Description	Origin	Score
Construction Systems	floor /wall/ roof systems	Cross Laminated Timber Panels (CLT)	Boards glued together in layers for two way spanning action and fabrication of large wall and floor elements.	Various	9.5
		Attic space panelised roofs (Smartroof, Intelli-roof systems)	Gable ended walls dividing townhouses are used as the support for long horizontal prefabricated panels so the roof space remains free for storage and/or room space.	Various	7.4

Table 3: Newly Identified ETs, Workshop 2 evaluations (continued).

Main Category	sub-category	ET Name	Description	Origin	Score
Construction Systems	floor /wall/ roof systems	Cree	CREE represents a hybrid timber-concrete construction system that is advanced, in so far as providing a complete engineered construction solution for medium rise buildings.	Austria	8.7
		Kerto (Metsawood)	Large panels of LVL type materials used for wall and floor panels.	Germany	7.0
		Kielsteg	Long span timber panels (up to 30 m) used for roof and floor situations made up of raked webs and solid top and bottom belts (made from scantling pieces).	Austria	7.6
		PHB wall and ceiling panels	Glue laminated sections which can be glued together offsite into larger panels (via double tongue and groove) then taken to site.	Germany	8.1
		HIB	Prefabricated wall panel/block hybrid where the two timber faces of the block are held together by very narrow jack studs. Assembly is similar to brickwork.	Germany	5.6
		Mid ply shear walls	Modification to traditional wall framing where the shear wall panel is situated between two studs turned "flatwise" for improved structural performance.	United States	7.7
		Expan – Quiet Floor	Panelised floor system with 8m spans. Two variants possible including timber only version and timber/concrete hybrid version.	Australia /New Zealand	8.2
		Expan (pre or post stressed) beam, post, frame, wall system	Pre or post stressed LVL/Glulam box beam sections for use in larger-scale buildings.	Australia /New Zealand	8.4
		Smart roof	Provides inexpensive provision of attic storage and room space via use of gable ended walls and prefabricated horizontal infill cassette panels.	United Kingdom	7.4

Table 3: Newly Identified ETs, Workshop 2 evaluations (continued).

Main Category	sub-category	ET Name	Description	Origin	Score
Construction Systems	Fire, sound & thermal insulation	Aerogel	Very high performance thermal and fire insulation that is thin, light and rigid	United States	7.6
		Flak jacket	Factory applied intumescent paint coating for I joists.	United States	6.9
		Heraklith wood wool	Panel product which uses wood wool on the outer skins with more conventional insulation in the middle to provide performance relating to sound and thermal properties.	United Kingdo m	6.5
Materials Tech'gy	Engineered & composite products	Carbodur	Carbon fibre sheet system that is glue bonded to timber beams to improve spanning ability and strength, and to repair existing structures.	Australi a (plus various)	6.6
Products & Materials Technology	Timber claddings, linings flooring	LP Top notch	Rain channel drainage notch is incorporated in the spline of platform flooring sheets to assist during construction.	United States	7.3
	Connectors& Fitments	Sherpa connections	Advanced timber connectors that are either hidden from view or are aesthetically minimalist, using high quality structural metal castings.	German y	7.8
		Expan – Quick connect	Timber sleeve and steel bolt connector capable of moment transfer capacity that allows easy fabrication of components offsite, then very fast and simple assembly onsite.	Australi a/New Zealand	9.0
		IWS – RIM steel plate connectors for timber	Pressed metal plate system to strengthen timber I-joists at services penetrations.	United Kingdo m	6.4
	Improved wood	Belmadur	Characteristics of the wood are noticeably improved via vacuum impregnated chemical treatment.	German y	6.8
		Medite extreme durability MDF	MDF that has undergone extensive performance testing and carries a durability class (under EN350-2) of 1, or very durable in external or moist environments.	United Kingdo m	8.0

Table 3: Newly Identified ETs, Workshop 2 evaluations (continued).

Integrated design and delivery concepts	**Building Information Modelling**	BIM and 5D CAD	Intelligent and integrated 3D master model of the building design with costs and production information linked to it.	Various	7.9
		Trimble's Filed link for structures	3D model of site and building are linked to hand held digital survey equipment which automatically provides setout points for columns, corners, levels etc.	United States	7.9
	Supply Chain Management	Structure craft	Contractor specialising in the integrated engineering, design detailing, supply and fabrication of complex, large and challenging timber structures.	United States	8.6
		Cut my Timber	Network of experienced timber engineers and fabricators who take a digital 3D design from the contractor and then use CAM and CNC equipment to produce complex shaped timber components for given projects.	United States	7.6

DISCUSSION

Floor, Wall and Roof Systems in Timber

As shown in Table 1 and discussed above, 24 of the 46 overseas Emerging Technologies that attracted higher scores concerned the use of timber for innovative ways of spanning distance. Like Laminated Veneer Lumber which enjoys widespread acceptance in Australia, they employ timber in ways which seek to overcome the material shortcomings of variability in the natural material. Many served beyond pure spanning ability and included the massive use of timber. Here, the highest scoring options provided wall and floor elements suited to prefabrication and forming the building super-structure.

More specifically, high scoring examples of "Mass-timber" technologies (such as Lignotrend, Brettstapel, Lignature, CLT) involve thick-panel systems which can be used with concrete and other materials to give good sound and thermal insulation characteristics and acceptable fire resistance. Many such systems cited the environmental credentials of the use of a large volume of low-strength timber as "locking up" much carbon. Several of the evaluation team however expressed an opinion that the timber supply in Australia may not be able to meet the volume required by large-scale adoption of mass-timber ETs. There was also a perceived lack of advanced timber element manufacturing and a lack of large project timber fabricator/erectors in the local market.

In some instances there are mitigating factors that potentially lessen this gap. Of note, systems such as Cross Laminated Timber require a relatively small capital investment to enable existing board plant to manufacture panelised CLT product. Hence, commodity-type panel material can be easily cut to customised shapes without creating a highly customised fabrication process. This has the benefit of a relatively low reliance on fabricators in the supply chain, who currently tend to be limited to simplistic prefabrication of stud frames and trusses. There is even the potential of a fairly direct manufacturer-to-contractor relationship in the supply chain. Consequently, CLT has strong potential to readily fit into existing market circumstances in Australia. Lend Lease's Forte Building (Lend Lease, 2013), reported to be the tallest timber building in the world, is made from imported CLT. Such buildings may act as a catalyst for local production of CLT.

While the focus of this work was to investigate the suitability of timber for use in Australian residential construction (predominantly individual detached houses), many of the ETs lent themselves to construction on a larger scale. This is understandable considering the generally lower emphasis on detached housing in most countries other than Australia. Some of the long span or prefabricated ET systems could (given regulatory evolution) have a greater role in the medium and higher density developments now appearing more frequently with urban consolidation in Australian cities. Members of the evaluation team expressed the opinion that some of the ET systems (such as cross-laminated timber) could also lead to a generally improved use of timber structure thereby offering the possibility of enhancements to the design of the predominant single dwelling houses built in this country.

Most evaluating experts observed that the construction system emerging technologies required extensive off-site industrial capacity and would require a substantial capital investment to be established locally. To justify the tooling cost for an ET (perhaps encouraged by a programme of medium-density developments using that ET), a revisiting of some state regulations would be required.

While off-site manufacture offers the expected economies and advantages associated with a quality-controlled industrial process, the evaluation group pointed to a change in industry culture that would be needed to adopt construction system ETs. Particularly for the larger scale projects for which would suit some ETs, contractors would need to commit to turnaround timing and training programmes which may include topics such as the management of tolerances and setout, handling procedures etc.

"Improved –wood" Material Enhancement Systems
Timber's natural susceptibility to dimensional instability and durability shortcomings have historically been sources of fear for designers. "Improving" the wood usually involves a chemical approach to prevent biological attack (e.g. against termites and rot) and stabilise shrinkage behaviour. ETs from Europe understandably don't devote sufficient attention to termite resistance for Australian conditions. Vacuum impregnation of acetyl type chemicals such as the Belmadur process and the "Medite" high durability Medium Density Fibreboard were well received by the evaluation group. Of the earlier group, Greenweld and Woodheart were seen as rational ways of obtaining improved structural performance from low-strength plantation softwood.

Of note, all these technologies improve the reliability and scope of timber usage, and therefore improve its competitiveness relative to other materials. Such features are underpinning qualities that make new generic markets possible for the material, but are distinct from the more advanced systems approaches discussed above.

Insulation Systems
While the four insulation Emerging Technologies examined (refer Table 1) were all fairly highly rated by the assessment group, no profoundly new ETs were identified. Issues associated with fire resistance and sound insulation have already been extensively canvassed by the timber industry. Timber is perceived as not having enough thermal and structural mass. Structure-borne and flanking sound can be challenging in multi-occupant timber buildings. There are perceptions of timber buildings' susceptibility to fire. Many of the construction system ETs incorporate opportunities to add insulation layers for sound and temperature and/or use of massive sections of timber for its inherent insulation characteristics and slow-burn fire resistance i.e. surface charring of large timber sections is known to provide insulation that protects against fast burning of timber – refer ???).

Connections and Fittings
Most designers are familiar with the challenges posed by joints in timber construction. Of the five such ET's examined (refer Table 1), two impressed the assessment group; Expan "Quick-Connect" frame connectors and the elegant and nearly invisible "Sherpa" wedge –lock connectors from Germany. The local industry has a track record of adopting steel connectors (eg. gang-nail connectors, nail plates, joist hangers etc.) for timber – it is possible that the connection ETs mentioned above will find applications in Australia that may see greater use of portal systems for domestic construction.

Integrated Service Delivery

Building Information Modeling (BIM) is likely to change the nature of the procurement and delivery process of buildings in the future. It is already mandated or highly preferred on government projects in the United States (GSA, 2013), United Kingdom (UK Cabinet Office, 2011) and Singapore (BCA 2011). At its core, BIM provides a base level technology that opens up new possibilities in the procurement, design and delivery processes – especially in terms of greater integration in the supply chain and an improved ability to interactively industrialise the design, fabrication and erection processes. The change point that BIM will bring, offers new opportunities for timber construction to move into new markets – such as the panelized construction mentioned above – because it will ultimately improve the ability to compare options, market integrated timber design and construction solutions and, simplify the uptake of offsite construction processes.

The two American supply chain management systems were well received by the second workshop group. In addition to providing a one-stop-shop for resources and services in timber design, both would offer support and encouragement for industry players who may be tentative about the risks perceived in using timber construction for more significant buildings.

CONCLUSIONS AND RECOMMENDATIONS

The completed project has culminated in a web based tool – containing high scoring ETs - for those interested in initiating innovative timber construction in the Australian industry (http://buildinginnovations.fwpa.com.au/). It aims to facilitate awareness and strategic debate about future innovation in the timber industry. In reality, the Delphi approach used in this study acts as part of an ongoing filtering mechanism, that has the potential to help focus debate and ongoing investment plans among corporate and industry decision makers.

Surprisingly, many of the local and overseas contacts who contributed had not encountered such an approach to creating awareness and assessing new technologies. They expressed the opinion that the process and resulting web site gave them a new insight and valuable overview of developments. An ongoing web forum - on a broader international scale - would provide a mechanism for sharing and even leveraging technology that may improve the commercial viability of a given ET.

High scoring and high frequency technologies from the evaluation phase of the project mainly concerned Structural floor/wall/roof timber systems – such systems mainly involved panelised construction. An issue that continually arose in debate about the above systems concerned the supply of sufficient wood, the relative cost of such systems and the supply chain necessary to deliver prefabricated panelized systems. Here, the need for appropriate fabricators and erectors poses a significant issue for certain systems within this segment. Further, it is apparent that one of the key issues prompting the use of such timber systems is speed of construction. If the Australian timber industry is to apply this to multi-story buildings, fabricators must be prepared to contractually commit to the faster time performance required on large multi-storey projects, albeit that this tends to be a significant step up in project risk compared to the low risk currently experienced by the small-scale residential fabricators that currently exist in the market.

A lower number of innovations than expected were found relating to dedicated fire and sound resistant timber construction, though to some extent, solutions for these issues were found to be inherent in the likes of mass timber structural systems and timber-concrete composite construction, alluded to under the panelised systems mentioned above. Even so, it would seem that any moves into larger building construction must accommodate fire and sound construction solutions and it is felt that the treatment of structure borne sound and flanking sound will continue to be important.

It is evident from the preceding discussion that not all of the 46 ETs identified in this study are likely to become staple technologies in the Australian timber industry - only a few may reach that status. It would therefore seem that the timber industry must in the early adoption phase agree on a limited number of new technologies and develop an agreed strategy that limits R&D overlap and process waste. Consequently, mechanisms whereby ETs can be adopted in Australia need to be examined at an industry-wide level. Treatment of commercial risk, capital investment, logistics, marketing infrastructure and entrepreneurship must be at the heart of the debate. This could be managed industry-wide in the early stages of development, then at a defined cut-off point transferred to individual companies – thus aiming to eventually promote open market competition.

Here, it may be worth considering the use of new organisational structures focusing on technology transfer. One example is the use of technology driven cooperatives as a means of implementation. Industry-based examples of this may be found in the likes of the agriculture and dairy industries where cooperatives have provided centralised equipment, supply chains and logistical processes for some time. Other alternatives involve the seed funding of start-up companies to nurture missing links in the supply chain and to deal with associated risk.

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REFERENCES

Adler, M., & Ziglio, E. (1996). "Gazing into the Oracle: The Delphi method and its application to social policy and public health". London: Kingsley Publishers.

Building and Construction Authority Singapore, BCA, (2011), Build Smart, [ONLINE] Available at: http://www.bca.gov.sg/publications/BuildSmart/others/buildsmart_11issue9.pdf, [Accessed 01 July 2013].

Dajani, J. S., Sincoff, M. Z. & Talley, W. K. (1979). "Stability and agreement criteria for the termination of Delphi studies". *Technological Forecasting and Social Change*, 13, 83-90. Dalkey, N. C. (1967). Delphi (Report P-3704). Santa Monica, CA: Rand Corporation.

Dalkey, N. C., & Helmer, O. (1963), "An experimental application of the Delphi method to the use of experts", *Management Science*, 9 (3), pp. 458-467.

Davidson, P., Merritt-Gray, M., Buchanan, J., & Noel, J. (1997), Voices from Practice: Mental health nurses identify research priorities, *Archives of Psychiatric Nursing*, XI, (6), 340-345.

Delbecq A.L., Van de Ven A.H. & Gustafson D.H. (1975) "Group Techniques for Program Planning: A Guide to Nominal and Delphi Processes". Scott, Foresman and Co., Glenview, IL.

Eggers, R.M. & Jones, C.M. (1998), "Practical considerations for conducting Delphi studies, the oracle enters a new age", *Education Research Quarterly*, 21 (3), pp 53-66.

Lend Lease, (2013) *Forte World's Tallest Timber Apartments Melbourne Docklands by Lend Lease*. [ONLINE] Available at: http://www.forteliving.com.au/index.html. [Accessed 01 July 2013].

Mitchell, P. & Tucker, S. (2011) – Investment plan for increasing the use of wood products in residential construction, Forest and Wood Products Australia, Melbourne

General Services Administration, GSA, (2013), *GSA's Journey into Building Information Modeling*. [ONLINE] Available at: http://www.gsa.gov/portal/content/102969. [Accessed 01 July 2013].

Goodman,C. (1987), "The Delphi Technique: a critique", *Journal of Advanced Nursing*, Vol 12, Issue 6 pp729-734

Green B, Jones M, Hughes D, Williams A. "Applying the Delphi technique in a study of GPs' information requirements". *Health Soc Care Community* 1999; 7:198-205.

Griffin-Sobel J.P. and Suozzo, S. (2002) "Nursing research priorities for the care of the client with a gastrointestinal disorder : a Delphi survey". *Gastroenterology nursing*, 25(5), 188-191

Keeney, S., Hasson, F. & McKenna, H. (2001), "A critical review of the Delphi technique as a research methodology for nursing", *International Journal of Nursing Studies*, 38, pp 195-200.

Keeney, S., Hasson, F. & McKenna, H. (2006), Consulting the oracle: ten lessons from using the Delphi technique in nursing research - *Journal of advanced nursing*, Wiley Online Library, 53, 2, 205-212

Keeney, S., Hasson, F. & McKenna, H. (2011), "The Delphi Technique in Nursing and Health Research", John Wiley and Sons, United Kingdom.

Lynn, M.R., Layman E.I. & Englebardt, S.P. (1998), Nursing administration research priorities: A national Delphi study, Journal of Nursing Administration, 28, 5, 7-11.

Mcilfatrick S.J. and Keeney S (2003) "Identifying cancer nursing research priorities using the Delphi Technique". *Journal of Advanced Nursing*, 42(6),629-636.

McKenna HP (1994) "The Delphi technique: a worthwhile research approach for nursing?" *Journal of Advanced Nursing*. 19, 6, 1221-1225.

Paevere P. & McKenzie C. (2006), "Emerging Technologies and Timber Products in Construction – Analysis & Recommendations", CSIRO, Melbourne.

Rowe G, Wright G, McColl A (2005), "Judgment change during Delphi-like procedures: The role of majority influence, expertise, and confidence, Technological Forecasting and Social Change" http://www.sciencedirect.com/science/journal/00401625,Volume 72,Issue4 http://www.sciencedirect.com/science/journal/00401625/72/4,May 2005, Pages 377-399

Stitt Gohdes, W.L. & Crews, T.B. (2004), THE DELPHI TECHNIQUE: A RESEARCH STRATEGY FOR CAREER AND TECHNICAL EDUCATION, Journal of Career and Technical Education, 20, 2, 55-68

Williams P. & Webb C. (1994) "The Delphi technique: a methodological Discussion". *Journal of Advanced Nursing* 19, 180–186.

UK Cabinet Office (2011), Government construction Strategy, UK Cabinet Office, [ONLINE] Available at: http://www.cabinetoffice.gov.uk/sites/default/files/resources/government-construction-strategy_0.pdf. [Accessed 01 July 2013].

Appendix A Scoring Instrument

Assessment of emerging technology: (insert name)	
Overall Perception Score	Score (0-10).......
Criteria/descriptors	
1 - Australian Context (likelihood of fit/changes req'd) **+ -** ☐ ☐ Specialist skills or equipment requirements:...................................... ☐ ☐ Regulatory/Deemed to satisfy fit: .... ☐ ☐ Network – uses existing supply chain... ☐ ☐ Network – uses local materials:	Score (0-10)...... Don't know ☐ N/A ☐
2 – Sustainability ☐ ☐ Resource renewability ☐ ☐ Waste/pollution implications: .... ☐ ☐ Carbon capture: .... ☐ ☐ Indoor Air quality/VOCs: .... ☐ ☐ Life cycle - operating energy/CO^2:.. ☐ ☐ Life cycle - embodied energy/CO^2:... ☐ ☐ Life cycle – end of life energy/CO^2: .... ☐ ☐ Life expectancy (replacement req'ts over 60 year design life):	Score (0-10)...... Don't know ☐ N/A ☐
3 – Project Cost/Time/Quality ☐ ☐ Cost – site labour/equipment/material/OH&S: .... ☐ ☐ Cost – Life cycle: .... ☐ ☐ Construction quality:.. ☐ ☐ Time onsite:	Score (0-10)...... Don't know ☐ N/A ☐
4 – Industry Design and Construction system improvement ☐ ☐ Work flow and productivity:.. ☐ ☐ Industrialised/prefab systems:.. ☐ ☐ Health and safety: .... ☐ ☐ Design adaptability/simplicity:	Score (0-10)...... Don't know ☐ N/A ☐
5 – Timber Market (supply side) ☐ ☐ Timber product volume/value: .... ☐ ☐ Ease/Effort/Barriers to market and realizing returns: .... ☐ ☐ Technical complexity to produce: .... ☐ ☐ Product support requirements: .... ☐ ☐ Business strengths/weaknesses/opportunities/threats:	Score (1-10)...... Don't know ☐ N/A ☐
5 – Material Performance ☐ ☐ Durability: .... ☐ ☐ Structural: .... ☐ ☐ Fire: .... ☐ ☐ Acoustic: .... ☐ ☐ Thermal: .... ☐ ☐ Weather/Water:	Score (1-10)...... Don't know ☐ N/A ☐
6 – Market (end user) ☐ ☐ Appearance/style: .... ☐ ☐ Functional features:	Score (1-10) ..... Don't know ☐ N/A ☐
7- Other Comments, Caveats and conditions V	**Optional** Score (1-10)......