ENGINEERED WOOD PRODUCTS - EXPERIENCE AND OPPORTUNITIES

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SUMMARY

Significant changes to the manner in which wood has been used in structural applications over the last 25 years are in response to reduced access to high strength timber from first growth forests, and the development and production of a number of new configurations of manufactured wood products. These materials, referred to as Engineered Wood Products are manufactured to use more of the available fibre resource with little waste, and also provide new potential for use both as primary and secondary structural components. The growth in the use of these products in North American construction is very strong, and is expected to continue into the 21st century.

1. INTRODUCTION

Wood has been an essential element of construction for centuries, with preserved examples of such structures dated to thousands of years B.C.[1]
This paper discusses North American experience, and in particular, some Canadian examples of the changing use of wood in structures with what have become known as Engineered Wood Products (EWPs).
North American designers have long called on timber resources from across the continent to provide structural wood components both in light wood frame and heavy timber construction.
Wood products dominated the light commercial market prior to the Second World War. Market entry and the eventual domination of steel and concrete in this sector came about due to a combination of factors, among them:

- decisions by the forest industry itself to respond to the post-war demand for residential construction. This shift in production strategy. essentially moved much of manufacturing away from larger sections towards dimension lumber,
- safety and code-related inducements to use non-wood construction related to fire issues,
- the increasing importance of engineering factors in material choices, and the fact that most engineering schools provided little education related to the use of wood in construction,
- a number of well focussed steel "turnkey" system approaches to the marketplace.

Traditionally, regional forests provided raw material to mills for manufacturing into joists, studs, and panel products. Variations in measured structural performance of different species and grades of lumber from different areas were reflected as well as could be assessed in grading rules administered by a number of grading authorities..
A very intensive full size lumber testing programme initiated in Canada in the late 1970's and replicated in the U.S. in the 1980's known as the In-Grade Testing Programme [2,3] proposed a number of changes in design values for both specie groups and grade categories. These recommendations are now included in current editions of grading rules and design codes in both countries.
Attention to dynamic and vibration criteria resulted in shorter span recommendations for dimension lumber in design codes.
The foregoing factors, the decreasing access to larger high quality logs, and industry commitments to better utilisation of harvests have been, in large measure, the impetus for the development of a variety of structural composite lumber products, or EWPs.
Initially, products such as the Wood I-joist, and Laminated Veneer Lumber beams and headers were used as flexural members. Increasing, these and newer products are being used as columns and wall elements as well.
Many new opportunities for wood components are only beginning to be realised. This paper looks at a new generation of wood products, manufactured from the only renewable structural material. These products can play an increasingly important role in an environmentally concerned world.
For the purpose of this paper, and in the absence of any other definition, the author set himself the task of phrasing a general description of the group of materials now called Engineered Wood Products. The following definition is suggested:
"those wood materials that have been manufactured or processed to prescribed standards to create new end-products intended for structural applications can be considered to be Engineered Wood Products".

2. ENGINEERED WOOD PRODUCT CATEGORIES

2.1 Glued-laminated timber

Glued-laminated timber, or Glulam, is the oldest member of the EWP family. Manufacture of this product began in Europe at around the turn of the Century, in the U.S..in the 1940's, and in Canada in 1952.
Glulam is manufactured to strict standards of material grading based on stiffness rating of the individual laminations which are machined to fine dimensional tolerances to ensure proper glue bond adjacent to the finger joints.
The process consists of mechanically end-jointing individual boards to create a lamination of the length of the finished member. These boards or laminates are then coated with adhesive and assembled into a package which is clamped for a prescribed period of time to permit the adhesive to cure.
After curing, the assembly is removed from the jig, planed smooth and then further finished by patching, sanding or framing for connectors as necessary.
Limits on the slope of grain for laminating stock and the fact that the size of any defect is no larger than the depth of an individual lamination contribute to a bending strength of approximately double that of the equivalent size of commercially available solid sawn timber. As well, improved shear strength is realised.
A number of different specie groups and grade combinations provide finished products of different strengths. Proper specification and product identification is important in using this material.
Glulam members can be manufactured to very long lengths. A recent bridge project completed in the U.S..included beams which were each 53 metres long, understood to be the longest ever produced.[4]
The relative ease with which glulam members may be manufactured to a curved profile allows them to contribute to the efficient construction of large storage buildings. Arched forms are well suited to community halls and places of worship.
Recently, fibre-reinforced polymers have been included in the manufacture of some glulam production. This component enhances the tensile performance of the member and is said to offer economic benefit in some applications.

2.2 Laminated Veneer Lumber

Laminated Veneer Lumber (LVL) is manufactured by laminating selected veneers in a parallel alignment. The product was developed in the late 1960's and has become well established as a high strength beam and header component in both residential and commercial construction. Because it is manufactured from veneers, LVL makes up to 35% more effective use of logs than is possible with solid lumber.
Individual defects cannot be thicker than a single veneer, and are distributed throughout the member. Consequently, a very uniform, high strength product can be manufactured from lower grades of small, young trees.
At manufacture, veneers are dried to 8% moisture content, and graded for uniform strength and width before lay-up. Adhesive is applied and the product is bonded under heat and continuous pressure until.cure. Billets of LVL, 45mm to 65mm in thickness, 1.2m wide and up to 25metres in length are then sawn into depths which are usually matched to either dimension lumber sizes or other EWPs such as standardised I-joist depths.
In the most common application of LVLs, individual 45mm thick plies are either nailed or bolted together to form wider beams or headers. Since the member is very dry at the point of manufacture, shrinkage and twisting in place is not a concern. Care must be taken to keep the product dry, and the manufacturing process usually includes application of edge and surface sealers to protect against exposure to wetting.
LVL is produced from a number of different species and grades, although specie and grade are not mixed in a given member. As a result, the bending strength and stiffness of these products will be determined by the make-up, and clear product identification is essential to match specification requirements.
The finished appearance may not be appealing as an exposed member, so concealed and industrial applications are favoured.

2.3 Laminated Strand Lumber (LSL)

The 1980's saw the development of technology that allowed the production a relatively strong structural member from low grade logs that would not normally be used for conventional wood products because they were not large, strong or straight enough.
In this process, the debarked logs are used to provide the material for flaked strands, which can be up to 300mm long. These strands are then dried, coated with resin, and pressed into large billets by a process which includes steam injection.
The billet may be up to 140mm thick, 2.4 m wide and 10metres long. After sanding, a large number of sizes are cut to suit applications such as headers, rim-joists for floor systems, columns, joists and studs.

A review of current manufacturer's literature indicates that the bending strength of LSL ranges from about 60% to 75% to that of LVL, depending on the grade being considered.

2.4 Parallel Strand Lumber (PSL)

This product was invented in Canada and following 20 years in development, made its way onto the market in the late 1980's.
Larger members, some approaching sizes common in glulam are manufactured by assembling small (3mm x 15mm) strands which have been chopped from sheets of veneer up to 2.4m long.
The strands are generally taken from veneers peeled from the outermost section of the logs, where stronger grain is located.
Veneers are dried to 11% moisture content and graded for strength before chopping into strands. They are then aligned parallel to one another, coated with a waterproof adhesive, then pressed and cured using a microwave process to form a rectangular billet up to 275mm wide, 305mm deep and 20 metres long.
The product is quite uniform throughout the cross section, and is re-sawn from the manufactured billet to quite an array of sizes. The varied profiles accommodate several applications. These include 45mm wide plies to serve as built-up headers in much the same way as does LVL. Wider widths (65mm, 133mm and 178mm) are well suited to longer span beams and headers.
Again, the even distribution of necessarily small defects in the individual strands allows for a considerably higher strength than is available from normally available solid timbers of the same cross section.
As designers and users become more familiar with this material, its use in trusses and other structural frames is increasing.

2.5 Wood-I Joists

In this product, the flexural efficiency of the steel I-beam is duplicated. Wood flanges of solid wood or one of the manufactured EWPs are arranged on the top and bottom of, and glued to, a vertical web of either plywood or Oriented Strand Board.
In the author's opinion, the introduction of the wood I-Joist has been the single most important advance in allowing wood-framed structures to be competitive to steel and concrete buildings. In these structures, the secondary framing component would be open web steel joists or concrete hollow-core slabs respectively. Prior to 1969 when the first commercially produced wood I-joists were available in North America, wood buildings which may have used heavy timber primary framing components quite competitively, found few options when it came to secondary framing.
The usual choices were to use side-nailed boards on edge (laminated decking spanning over the beam),.or dimension lumber as joists. Both. arrangements usually limited main member grids to inefficient spacings. Another option was to use secondary beams with a tongued and grooved wood decking overlay.
Often these floor systems squeaked due to even small relative movements as loads were applied, and as such, they were not considered acceptable from a performance point of view.
The wood I-joist is a lightweight, dimensionally stable, long span secondary framing component which is predicable in performance, manufactured to close tolerances, easily transported to site, and can be easily trimmed and installed on site by a carpentry crew.
Again, as a manufactured wood product, the component materials are relatively dry, and there is no expectation of in-place seasoning which will lead to dimensional change or nail squeaks.
Different manufacturers include a range of widths and depths of machine stress rated solid wood or LVL flanges combined with different thickness and grades of Oriented Strand Board or plywood webs.
It is possible to pass quite large mechanical ducts and services thought the web of the joist, subject to compliance with the manufacturer's published limitations that respect the performance of the individual product.
The wood I-joist uses forest resources very efficiently. The typical Canadian home consumes about 24m^3 of softwood lumber, including material for trim, sheathing and finishes. Of the total, 9.6m^3 is used for roof and floor joists. By substituting wood I-joists for these components this volume is reduced to 2.9m^3, a 60% saving of wood fibre.[5]
Not only does the joist integrate well with heavy timber construction, many projects have demonstrated that it can serve well as the secondary framing for buildings framed with steel.
Wood I-Joists are manufactured in depths ranging from 250mm up to about 900mm. Floor spans of up to 15 metres or so can be handled by the deeper products.

2.6 Structural Plywood

Plywood is manufactured from stacked veneers which are arranged in an odd number of layers, the grain of the face layers oriented to the long dimension of the panel. The cross-laminated lay-up of the veneers gives strength, stiffness and dimensional stability. Plywood is used extensively in diaphragm and shearwall construction, as well as a web component of the wood I-joist.

2.7 Oriented Strand Board (OSB)

In the manufacture of OSB, wood strands of about 75mm in length are bonded with adhesives to form a mat. As with plywood, the mats are layered and oriented for maximum strength and stiffness. This material is gaining importance as a structural component in shearwall and diaphragm construction, and is now the most common web material in wood I-joist manufacture.

2.8 Other wood-based products which are engineered in manufacture.

A number of combinations of different materials and configurations of both flange web assemblies are currently manufactured. Whilst these are not generally classified as Engineered Wood Products, they are, nonetheless,. wood products that have been engineered in manufacture.

Among this group are:

- Light metal plate connected wood trusses
- Wood flange/metal open web flat trusses
- Wood flange/wood open web flat trusses
- Stressed skin panels and boxed beams

This paper will not discuss these products in detail, but the following general comments are appropriate:
Light metal plate connected trusses, which connect wood chord and webs with toothed metal plates provide a very efficient use of wood fibre in resisting load. They have found a solid market in residential roof framing, and both roofs and floors in commercial applications. The design of the members and plates is usually by the fabricator using proprietary programmes prepared by the plate manufacturer.
Wood flange and metal open web trusses are manufactured as either parallel chord assemblies or to sloped or curved profiles. These products can span over 20 metres, and again, are usually engineered by the manufacturer.
A Canadian manufacturer has developed a series of flat trusses which incorporate wood web members in the much same manner as the steel cousin. In this case however, the webs are connected to the wood flanges by finger joints.
Stressed-skin panels and boxed beams, which previously used dimension lumber as stringers and blocking, can realise new potential as larger components as some of the EWPs discussed here become part of the assembly.
Floor diaphragms and shear walls constructed from panel products and one or other of the available wood framing options will serve to transfer lateral loads to the foundations.
In many cases, a wood framed structure will considered more viable if all the components are wood-based because the carpentry crew can handle all the work and the number of trades on a project is reduced.

2.9. Connections

The different make-up of.the various EWPs means that different approaches need to be taken to connections in each. This is a sorting-out period as testing of various fasteners in EWPs is underway..
Bearing type hangers are satisfactory for all groups. Calculations by the designer to determine required bearing lengths, or simply following tables in the EWP producers' literature will allow the selection of an appropriate hanger from several hanger manufacturers who have developed lines of products to serve the market.
Table 1. summarises the current situation with respect to fasteners which manufacturers have deemed suitable for use with their beam and header products.

	Glulam	**PSL**	**LVL**	**LSL**
Shear Plates	YES	YES	NO	NO
Split Rings	YES	NO	NO	NO
Timber Rivets	YES	YES	NO	NO
Common Nails	YES	YES	YES	YES

Table 1-Summary of Fasteners currently deemed suitable for use with various EWPs

3 APPLICATION OPPORTUNITIES AND SOME OBSTACLES

3.1 New opportunities

The group of Engineered Wood Products discussed has, by now, become well established in North America as a readily available material resource. Many are available through not only the specialised heavy timber framing companies such as glulam and proprietary product producers, but distributed by local lumber yards as well.
There are major sectors of construction that can now be better served by wood structural systems as a result of the larger choice of high strength beam and column products and an even wider selection of secondary framing products described here.
Clearly there are limits to the extent to which wood construction can serve multi-storey units, and buildings where code restrictions to combustible construction apply. However, the experience of the author in working with timber structures in North America for over 30 years shows a significantly greater interest in considering wood as an option for structure, and an increasing appreciation of the potential for what can be achieved by building with this material.
Today, there should be very few instances when a wood framing option should not be able to present a practical and competitive solution to commercial buildings that would normally be framed in steel or concrete.
However, a recent Canadian Wood Council study estimated that 52% (by dollar volume of building permits issued) of non-residential construction in Canada was suited to building with wood products with respect to compliance with current codes and jurisdictional acceptances. Only 15% of that potential market is currently being constructed in this way. Based on this assessment, it is not difficult to recognise the potential for growth in this sector.
Some of the developments now underway that should allow this increase in market share to happen are:

- the improved availability of the range of EWPs discussed,
- greater promotional efforts by wood industry associations and many individual product manufacturers to bring project examples and case histories of successful applications to the attention of designers,
- the development of design aids and software to assist in the selection of products, and the actual design of members,
- the improved availability of standardised hangers and member connection hardware,
- an increasing number of companies with skills and experience in the framing and installation of EWPs.

Whilst there is reason to be optimistic about what is seen to be a growing market, we need to recognise that some designers determinedly steer away from choosing wood as structure..

3.2 Some obstacles to wood use

There remain concerns among specifiers and designers about quality of product, seasoning effects such as shrinkage and twisting which may affect finishes, and an opinion that there are a limited number of companies capable of providing a properly engineered package..
The specialised equipment and resources required to fabricate and install structural steel or to engage in larger scale commercial concrete construction are not required on many timber framed projects..
As a result, work can be taken on by companies without much technical resource or with un-skilled workers may who not employ good wood engineering and detailing practice. The perception that such work may not be done well is a cause for hesitation at the time of material specification.
Further, as a result of the scant time assigned to wood technology and design courses in universities and colleges, most designers have little knowledge of procedures for either member or connection design. The effect of this major shortcoming is particularly significant at the early project design stage when the architect and engineer meet to consider the client's requirements.
At this point of the design, they call on their collective knowledge of structural materials and their previous experiences with each to lead them to recommend a particular choice of structure for the work.
It is quite understandable that within the available (and usually very competitive) fee structure, a consultant will be more likely to recommend a design to include those products with which the design team is most familiar, and can define quickly and with the greatest confidence.
As discussed earlier in this paper, designers often consider buildings constructed of timber to be too expensive. This opinion may have been formed because of a previous experience with a structure that had an efficient layout or was constructed with a poor selection of materials.
In the past, manufacturers of structural timber components have tended to promote their own product mix as the total solution to the framing requirements of a particular project. This was certainly to the advantage of their own order files, however, the products produced by that company may not have been the most efficient for the application. Consequently, buildings which may have benefited from the inclusion of other wood products from another industry source were less cost effective than they could have been.

The steel and concrete industry have been much less proprietary based in their approach to the market, and a building was classified as "steel or concrete" rather than having been supplied by a particular manufacturer whose own products did the whole job.
Recent experience has shown that when a project draws upon an expanded source of wood products from different manufactures whose particular part may be a better fit in the total package, the final wood system is more competitive.

3.3 Comparing material options

In considering the use of engineered wood products for a building, the designer is presented with a stable of material choices which allow considerable potential for the expression of sculptural form. This opportunity to create a showpiece, when taken, often results in a timber structure whose elegance and beauty is truly a complement to function.
It is important that the wood industry continue to promote the benefits of the unique character and warmth of the exposed structural products. At the same time, it is equally important to be aware of the premium associated with the supply of often-elaborate shapes and treatments.
These may engage structural components as architectural elements in a manner that employs significantly more material that is required to support a given load. To properly assess the costs of wood versus steel solutions, one must recognise such considerations. All too often, a wood option is set aside because of such faulty comparisons.
For example, a school whose structural system, in the mind of the designer, will be well enough served by a structural steel frame and open web steel joist system should not simply be built that way because a heavy timber post and beam system is more expensive. The Engineered Wood Products discussed in this paper now allow the wood industry to compete with comparable products to the steel option.

3.4 The Environmental Challenge

The different sections of this paper which describe various EWPs.refer to the optimised use of logs due to the use of small sections, in many cases veneers or strands.
EWPs bring significant benefits compared to competing products such as steel, concrete and aluminium in terms of embodied energy, and emissions of carbon dioxide and other pollutants during manufacture and extraction.
Effective marketing of these messages should strengthen the position of EWPs as a preferred choice for construction in.the future.

4.0 COMPARING COSTS OF ENGINEERED WOOD PRODUCTS

In order to provide some relative measure of the costs various beam and header category of EWPs, Table 2 shows current Toronto, Canada price levels for a sample grouping of un-framed products in groups of sizes which serve different applications.

4.1 Consumption and projections

There has been growth in the production of all groups of EWPs, and projections for rapid growth in the LVL and I-joist sector are very strong.
Presently, about 50% of LVL production is as flange material for I-joists, the other half is manufactured into beams and headers.[6]
80% of wood I-joists are used for floors in residential construction, 10% for non-residential, and the remaining 10% divided among remodelling projects and roof joists.[6]
Use of I-joists for residential wood floors is expected to increase from 26% of built floor area in 1996 to about 50% by.2000.[6]
Table 3. shows the North American experience since 1980, and a projection of what is expected over the next few years.

Material selections for typical purlin applications.

Span	Snow load	Dead load	Spacing	Deflection limits			
5m	1.48kPa	0.7kPa	2.0m	SL	Span/360	TL	Span/180

Material	Grade	Member size	Cost ($/sq. m)	Meets Heavy Timber rating.	Seasoned	Comments
Solid Doug Fir	No 1	140x241	$15.38	Yes	No	"Stock availability limited, checking likely, shrinkage likely"
Fir Glulam	20f-E	80x304	$19.10	Yes	Yes	Stock to 2 week availability
Fir Glulam	24f-E	80x304	$20.05	Yes	Yes	Stock to 2 week availability
SPF Glulam	20f-E	80x304	$16.34	Yes	Yes	Supplied from stock from some manufacturers
PSL	2.0E	68x302	$13.61	No	Yes	"Standard product supplied from stock, plant markings"
		133x241	$21.40	Yes	Yes	"Standard product supplied from stock, plant markings"
LVL	2.0E	44x356	$10.70	No		"Supplied from stock, plant markings, sometimes coated"

Material selections for longer purlin applications.

Span	Snow	Dead	Spacing	Deflection limits			
7.5m	1.48kPa	0.7kPa	2.0m	LL	Span/360	TL	Span/180

Material	Grade	Member size	Cost ($/sq.m)	Meets Heavy Timber rating.	Seasoned	Comments
Sawn fir	No 1	140x394	$27.87	Yes	No	"Stock availability limited, checking likely, shrinkage likely"
Fir Glulam	20f-E	80x418	$26.26	Yes	Yes	Stock to 2 week availability
Fir Glulam	24f-E	80x418	$27.51	Yes	Yes	Stock to 2 week availability
SPF Glulam	20f-E	80x456	$24.80	Yes	Yes	Supplied from stock from some manufacturers
PSL	2.0E	89x406	$24.00	Yes	Yes	"Standard product supplied from stock, plant markings"
LVL	2.0E	2/45x406	$24.00	No	Yes	"Supplied from stock, plant markings, sometimes coated"

Material selections for beam applications

Span	Snow	Dead	Spacing	Deflection limits			
10.0m	1.48kPa	0.7kPa	4.5m	LL	Span/360	TL	Span/180

Material	Grade	Member size	Cost ($/sq. m)	Meets Heavy Timber rating.	Seasoned	Comments
Sawn fir		No selection				
Fir Glulam	20f-E	130x646	$27.05	Yes	Yes	2 week availability
Fir Glulam	24f-E	130x608	$28.40	Yes	Yes	2 week availability
SPF Glulam	20f-E	130x684	$24.80	Yes	Yes	2 week availability
PSL	2.0E	133x610	$24.50	Yes	Yes	2 week availability
LVL		2/89x610				Not readily available not too practical an option

Material selections for longer beam applications

Span	Snow	Dead	Spacing	Deflection limits			
15.0m	1.48kP a	0.7kPa	6.0m	LL	Span/360	TL	Span/180

Material	Grade	Member size	Cost ($/sq. m)	Meets Heavy Timber rating.	Seasoned	Comments
Sawn fir		No selection				
Fir Glulam	20f-E	175x1178	$49.33	Yes	Yes	2 week availability
Fir Glulam	24f-E	175x1102	$51.80	Yes	Yes	2 week availability
SPF Glulam	20f-E	175x1178	$42.72	Yes	Yes	2 week availability
PSL	2.0E	178x915	N/A	Yes	Yes	3 week availability
LVL	2.0E	No selection				

Table 2: Relative Costs of Comparable Engineered Wood Products (Toronto, Canada)

Year	Glulam (MMBF)	I-Joist (MM L.F.)	LVL (MM C.F.)
1980	214	50	3
1981	199	50	4
1982	172	60	4
1983	201	70	5
1984	240	80	5
1985	258	100	7
1986	346	110	8
1987	292	120	9
1988	312	120	11
1989	337	130	12
1990	339	135	16
1991	277	175	16
1992	270	280	17
1993	250	398	21
1994	276	422	23
1995	295	397	28
1996	322	498	32
1997	315	627	38
1998*	285	750	42
2002*	337	1050	73

***projections**

Source APA - The Engineered Wood Association, August, 1998

Table 3: North American production for some Engineered Wood Products 1980-1997

5. CONCLUSIONS

The development of new configurations of structural wood products – called Engineered Wood Products - over the last 25 years has made more efficient use of wood fibre and permitted the wood industry to compete with other building materials in more construction applications. Current experience indicates strong potential for future growth.

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