A Cradle-to-Cradle Approach to Timber Post and Beam Structures

Investigating the possibility of a Cradle-to-Cradle Platinum-Certified timber beam solution for long spans

AR0531 Innovation & Sustainability
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Yu Feng Wong

4631579
Y.F.Wong-1@student.tudelft.nl

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Abstract – The Cradle-to-Cradle Certification at Platinum level, awarded to products which perfectly embody the principles of Cradle-to-Cradle design, is perhaps one of the most esteemed standards of excellence in sustainability circles. Currently, there is no Platinum-level product which can deliver the classic post-and-beam structural system. This literature review investigates the possibility of a timber beam product filling in that gap, and the potential design specifications necessary to do it. Findings suggest that the resin component of current glulam beams harm the Cradle-to-Cradle assessment rating, therefore posing a challenge to find eco-friendly alternative. Potential candidates such as lignin and casein resin are studied, along with the novel technology of welded dowel-laminated timber.

Key words – cradle-to-cradle, laminated timber, renewable resin, glulam, dowel laminated, AR0531

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1 Introduction

The Cradle-to-Cradle Movement

The Cradle-to-Cradle approach to sustainability idealises materials as nutrients, flowing through either technical cycles or biological cycles. Unlike predecessors, this modern approach to sustainability aims to contribute positive effects to the ecosystem, as opposed to reducing negative ones (McDonough & Braungard, 2002). Therefore, it is key to a future of both economic and ecological prosperity, two concepts often viewed antagonistically.

The Cradle to Cradle Products Innovation Institute awards certificates to products of manufacturers which are assessed in five categories. A Platinum level certificate represents a virtually perfect score in Cradle-to-Cradle sustainability terms, which so far has been obtained by only one product, a timber cladding element. In the last few years, LEED and BREEAM-NL assessments started to reward the presence of such certified products.

Timber: The Sustainable Structural Material

		Mass in kg	Energy in kJ	CO_2 balance in kg
1 kN/m, 3 m	Timber	30	30	-50
	Steel	30	1 800	20
	Concrete	300	1 800	110
3 kN/m, 3 m	Timber	100	100	-160
	Steel	60	3 600	40
	Concrete	300	1 800	110

Figure 1: A comparison of the three main structural materials regarding energy consumption and CO2 footprint (Mouterde, 2011)

From the beginnings of architecture until about two hundred years ago, timber was the prime structural material for large spans. In the modern era, long-span beams have mainly been the preserve of concrete and steel. However, vast recent innovations of the last fifty years have brought timber beams back into the arena, expedited by improved lamination technologies, development of derivative products and growing pressures for sustainability.

Of the three materials, timber requires the least energy to produce and it is the only one which is carbon-negative (see Figure 1). Producing a single cubic metre of glulam releases about 207 kg of CO2, but contains 1010 kg of sequestered CO2 (Puettmann, Oneil, & Johnson, 2013).

A Platinum-certified Structural Element

Figure 2: Accoya Wood, a biodegradable treated timber product. It comes in Radiata Pine and Alder species of wood ("Cradle to Cradle Certified Products Registry," 2010)

Figure 3 Thoma Holz100: connections are entirely made using dowels ("Cradle to Cradle Certified Products Registry," 2010)

Currently, there are no Cradle-to-Cradle Platinum-certified post and beam systems of large spans (greater than 8 metres). Two Gold-certified products come close: the *Accoya® Wood* by Accsys Tehcnologies and the *Thoma Holz100* by Thoma Holz Gmb ("Cradle to Cradle Certified Products Registry," 2010). The former is a biodegradable treated sawn timber material of high durability (see Figure 2). The advertised applications are primarily joinery, but larger structures have been delivered via glulam bonded using PVAc, which is based on non-renewable petrochemicals ("Accoya-Jowat-Brochure," 2015). In certification terms, Material Reutilization has been sacrificed for Material Health.

The latter product is a timber solution for wall and floor plates composed of sawn timber held together by dowel joints to entirely avoid the use of glues or metal connectors. However, it is presented as an all-in-one planar component for simultaneously providing thermal, cladding and structural functions as opposed to a skeletal structural system (see Figure 3).

Consequently, there is a niche for a Platinum-certified product which can deliver the classic post and beam structural system. This literature review therefore seeks to answer the question:

How might a long-span timber beam be designed to deliver a product worthy of Cradle-to-Cradle Platinum-level certification?

In the first part of this review, the Platinum-level objectives which are relevant to the physical design will be studied. The shortcomings of conventional glulam timber beams will then be identified, and then potential design solutions will be pursued by studying technical literature. In this way, a conclusion will be drawn regarding the probable design of a truly sustainable long-span timber beam.

2 Methodology

The Cradle to Cradle Certified™ Product Standard, found on the institution's website, provides an in-depth description of the necessary requirements for Platinum ratings. The criteria relating to the design of the physical product were studied and compared to the EN standards of conventional glulam beams, found on connect.nen.nl. Alternative methods of procuring a beam were investigated, such as replacing the resin with more eco-friendly bonding methods.

When reviewing such technologies, search queries such as "timber resin", "sustainable glulam" and "sustainable laminated timber" were applied to GoogleScholar, Web of Science and TU Delft Library databases. Particular focus was placed on A. Pizzi, a leading authority who authored several books and dozens of papers regarding timber bonding innovations over the last few decades. It was useful to track the latest developments of the technology, as well as the predictions regarding future innovations and aspirations, which had varying levels of accuracy. Sources were cross-checked with each other to gain a coherent image and those with a high frequency of being cited were deemed especially trustworthy.

3 Results and Discussion

The Cradle to Cradle Certified™ Product Standard

The Cradle to Cradle Product Standard provides an in-depth outline of the requirements to ensure that the sphere of activity contributing to the existence of the product is sustainable ("Cradle to Cradle Certified Product Standard: Version 3.1," 2016). They are split into the following five categories:

- Material Health,
- Material Reutilization
- Renewable Energy and Carbon Management
- Water Stewardship, and
- Social Fairness

Some of the content in all five criteria focus on the strategic management, factory environment and social context, so are not relevant to the physical design.

Relevant points are summarised:

Category	Platinum-level criteria relevant to the product design
Material Health	No known or potentially harmful substances within the product (the Institute maintains a list of Banned Chemicals which should not appear in a Platinum product)
Material Reutilization	Eliminate the concept of waste: ensure materials are recyclable, biodegradable, rapidly renewable
Renewable Energy and Carbon Management	All greenhouse gas emissions are offset; Energy inputs for manufacture are renewable or offset
Water Stewardship	Water leaving a production site must be drinking water quality
Social Fairness	The production processes do not harm the health and safety of workers, for example by exposure to toxic chemicals

Conventional Glulam Beams

In C2C terms, glulam beams are monstrous hybrids. They are composed of sawn timber lamina, which are bonded together using resin adhesives, of which three common types are listed in the EN standard (Normalisarie-instituut, 2013):

- Polyurethane adhesives
- Emulsion polymer isocyanate adhesives
- Phenolic and aminoplastic adhesives

Polyurethanes, the first type, are produced using an isocyanate as a reactant (Parker, 2005). Isocyanates, the second type, are based upon formaldehyde (Frazier, 2003). Phenolic resins are the products of a reaction involving formaldehyde (Pizzi, 2003a). Finally, aminoplastic resins generally refer to urea-formaldehydes, the most important and used class (Pizzi, 2003b). Therefore, in every case, formaldehyde plays a crucial role in the production of the resin. The C2C Material Health Assessment Methodology states that this is a confirmed human carcinogen with a high acute toxicity ("Cradle to Cradle Certified Product Standard: Material Health Assessment Methodology," 2013). As such, it cannot be present in a Platinum-certified product. Additionally, it would damage the Social Fairness rating due to the danger it presents to workers exposed to it. There is likely a negative impact on Water Stewardship too, due to the intensive chemical processes which indirectly involve water.

Additionally, the carbon emissions due to the resin component of glulam is substantial for such a small percentage volume; a CO2 emission reduction of 16% is possible if conventional resins are replaced with natural alternatives (Bribián, Capilla, & Usón, 2011).

Eco-resins

A promising subset of adhesives are those that are organic and renewable. In 1929, Truax describes the height of timber glue technology: casein, animal, liquid, vegetable and blood glues (Truax, 1929). Interestingly, the use of such glues were displaced by the modern synthetic varieties as a result of WWII technological developments, had a temporary resurgence of interest during the oil crisis of the 1970s and today finds attention once again due to concerns regarding sustainability and unreliable petrochemical supply.

From about 1930, casein glues (derived from milk) have been successfully utilized in glulam beams for interior and covered exterior situations (Hemingway & Conner, 1989). Once used for Medieval furniture, it is notable for its water-resistance and gap-filling ability. Lambuth describes two of its best performance attributes owing to its stickiness: it can be applied up to two hours before clamp application and wipe resistance, allowing for easier large-scale clamping operations in the factory (Lambuth, 2003). Ultimately, casein was displaced by phenol-resorcinol-formaldehyde adhesives, which has superior weather durability. In the 21st century, the use of casein is limited; only four to five kilotons were imported into the United States per year in 2001 and its main use was in door joinery (Sellers, 2001).

Casein represents a promising avenue for a Platinum-certified glulam product; however, the processes and additional chemicals used would have to be carefully designed and analysed to ensure the achievement of the criteria. Currently, various chemicals are added to casein for better performance, fungus protection and consistency (Lambuth, 2003).

Lignin is the second most abundant matter in plants after cellulose. It is an abundant waste product from the pulp industry, and therefore represents a great reutilization opportunity in the material cycle if used for resin production. However, following over a hundred years of considerable research and development to produce a promising adhesive, it has yielded no commercial success (Hemingway & Conner, 1989). Issues stem from the low purity, quality and inconsistency of the substance.

Many patented processes have attempted to improve the performance of lignin bonding, but at the price of long or high-temperature gluing times or the application of mineral acids. A paper from 1985 comments on the dream of inventing a much sought-after lignin-based wood adhesive free from economical, technical or handling drawbacks (Klashorst, Cameron, & Pizzi, 1985). Under the current technologies, the adhesive is useful as an extender in UF and PF resins (making up 10-30%). Useful formaldehyde-free mixes which also employ other organic substances such as tannin and soy protein are still under development, but the application is in small-scale joinery and panels (Dababi, Gimello, Elaloui, Quignard, & Brosse, 2016) (Luo et al., 2015).

Dowell-laminated beams

An alternative to the traditional glulam beam exists in the form of resin-free dowel-laminated beams. Once again, it is a new development on old technology, as dowels were the primary method of structural wood connection before the 19th century widespread adoption of nails.

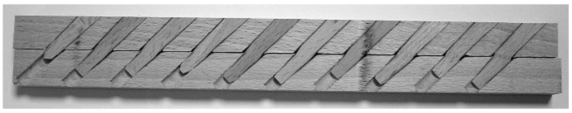

Figure 4: A cut section of a dowell-laminated beam (Bocquet et al., 2012)

A recent study tested the structural performance of 'dowlam' beams combined with a new technology (see Figure 4). The dowels were applied with high-speed rotation, which secured a 'welded' connection between the dowel and the laminae. This is thought to be caused by a melting and flowing of inter-cellular polymer material within the wood, perhaps lignin or hermicelluloses (Pizzi, 2005). The bonds were further enhanced by heating the dowel to 100°C and ensuring the dowel had a lower moisture content than the lamina so that it absorbed moisture and expanded inside the hole.

The results showed that the 'dowlam' beech wood beams had a lower failure force than both Melamine-Urea-Formaldehyde glulam beams and solid beech wood, but are very acceptable for European standards (Bocquet et al., 2012).

The concept of a dowlam beam is very practical in C2C terms; only the timber material features in the composition of the end product, thereby scoring very highly in Material Health and Material Reutilization. Future innovations might find stronger dowel welding techniques. Additionally, there may be opportunities to improve structural performance by local positioning of dowels, in the same way that rebar in concrete is positioned.

Conclusion

This literature review sought to find design solutions for a long-span timber beam that could satisfy the requirements of Platinum-level Cradle-to-Cradle Certification. It found that adhesives in glulam were harming the Material Health and Material Reutilization scores.

The possibility of two renewable organic adhesives were investigated. Lignin-based resins have found success as an extender of formaldehyde-based resins, but as an ingredient in a completely renewable and toxic-free resin, it is not yet strong enough for glulam applications.

Casein-based resins were the original binding agent at the invention of glulam beams, but has largely fallen out of use today. For a given mix which conforms to today's standards, an assessment needs to be done to ensure the processes and additives conform to the C2C requirements.

Dowell-laminated beams combined with high-speed rotational timber welding provide a compelling alternative. These beams are currently weaker in bending than typical glulam, but are acceptable for European standards. The science behind timber welding is not fully understood, so further research may be fruitful.

In all cases, research is still ongoing and indicates hope for a functional and truly sustainable long-span timber device, at least for one which is kept sheltered from the elements.

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