Sustainable Lightweight Façade Systems

B.M.Dowdle & C.D.Ross
Aurecon Building Sciences

Much of the materials that we use today in the construction of modern buildings has been processed and transported many kilometres resulting in high embodied energies and CO_2 emissions. The materials are largely won from non-renewable sources, processed and transported using non-renewable fossil fuels all greatly contributing to the production of greenhouse gases.

In this paper we have looked at 2 common areas of building facades to see how alternate materials can be employed to reduce the environmental impact that facade may have on the construction and operation of buildings.

The impact of facade on the Sustainable rating of a building is considerable (depending on form and shape – ie volume to enclosed areas). The facade components that we have considered often employ high embodied energy materials and they directly influence the operation of the building thereby affecting both operational energy (greenhouse gases production) consumption and occupant health and comfort.

The facade is essentially the image of the building and therefore acts as a metaphor for the building and fulfils an educational role. People visually associate the appearance with the intent, for example green buildings often have a design intent that is apparent.

Figure 1 Frasers Broadway - Green Facade

Facade Typologies

We have considered 2 typical facade typologies common used, we have described these below in terms of, intent or purpose and description, typical dimensions, structure, manufacture and materials

Curtainwall: Provides protection and filtering of external environment, is comprised of *repeatable prefabricated modular* units to envelope building (ranging from 3,000 to 40,000sqm) with typical dimensions of 1.2m to 1.5m wide up to 2.4m in width, spanning floor to floor 3.7m to 4.2m. The panels interlock to share applied loads, have minimal site lines, provide weather resistance, thermal flows and safety in operation. Furthermore facades define the aesthetic of the building, are generally made from aluminium framing, high performance glass with coatings, sealants, gaskets, insulation and sometimes incorporate a feature (fin, blade, louvre, light, etc). Variants including site installed windows in solid wall are not considered here.

Feature Glazing : Incorporating entries and glazed roof. Provides protection and filtering of external environment at entry, provides signature to entry of building, typically comprised glazed units installed in-situ to large span structure 8m to 15m at 2 to 3m centres, provide identity to building. Structural frame made from a variety of materials include mild seel, stainless steel, glass, aluminium and/or timber.

Typical materials used facade systems

In order to understand the benefits of new materials we need to understand the materials currently used in faacdes, these include;

Steel has successfully been used in large span glass walls and roofs, lightweight structures can be achieved when post tensioned. In facades it is used largely as connections and components because of ease of fabrication. Steel has a long history of design understanding and codified rules that provide confidence in design. The particular elastic and plastic ductile behaviour of steel allows for long span lightweight structures. Steel is an alloy formed from minerals mined and processed, which are energy intensive the resulting embodied carbon content is relatively high. Steel can be recycled but as it does not offer any opportunity for the sequestering of carbon.

Aluminium is typically used as framing for curtainwall and windows rather than large span facades as it can be extruded efficiently to achieve shapes that allow interlock and air infiltration requirements. Easily machined and joined. Aluminium has good strength to weight ratios but is limited use in connections and components in glazed walls as high strength connections are difficult to achieve. Various alloys are used, but has limited ductile behaviour and codified design rules allow widespread use and understanding. Constituent elements are mined and it suffers from high energy conversion process to change bauxite from ore to alumina. Many countries have constructed hydroelectric scheme just to power the alumina industry and 14% of Australian Greenhouse gas production is associated with alumina industry. Recycling of structural grade aluminium exists but susceptible to cross contamination. Generally up to 96% of all aluminium is recycled, it has the same issues as steel in terms of sequestering carbon.

Figure 2 Surry Hills Library Structural Glass Wall

Glass: is a material of ambiguity. It is a material that is largely used as the infill elements in windows and curtainwall. The unique internal structure of glass provides the unique property of a solid (glass) but one that is transparent allowing its extensive use through buildings. It provides access to light and a connection with the world while "providing a barrier to (some) heat, air flows and providing protection. The transparent but "solid" (load transfer) nature of glass allows for an invisible "lightweight" structure to be developed. Glass has been used in a number of projects as stiffening element for curtainwall and extensively in feature wall glazing as the entire structural and load bearing element. Glass is highly elastic but brittle nature permits in principal easy design but requires special attention in analysis of results, connections, redundancy, ductility and design philosophy. Glass is largely comprised of silica (the world's most abundant solid element), lime and soda ash. While it does occur naturally in limited forms, modern manufacture has high energy consumption. Un-coated products can be recycled and reformed into lower grade products. Structural and architectural glass requires virgin materials to achieve level of quality and clarity expected. Glass production does not sequester carbon and operational energy for building use is impacted on directly by glass selection.

Timber facades have been traditionally used throughout the world in small scale projects typically windows however, the interlocking details, joining seals, types of finish etc limit the use of timber systems to the domestic situations. Timber use historically revolved around local species of tree having low carbon footprint form low processing and local nature. Carbon is sequestered during growth of timber but is slow to regenerate and impacted by crop rotation policies. Larger spans are achieved through laminating processes of diced and rejoining materials to achieve stronger, longer, and more dimensionally stable materials..

In this paper we wish to consider and propose an alternative material – **Bamboo**

Figure 3 Bamboo Stand

Figure 4 Use of bamboo as a lightweight screen

Bamboo plants are giant grass-like plants and not trees as commonly believed and belong to the family of Bambusoideae. There are about 75 genera and 1250 species worldwide with total bamboo areas about 22million hectares and a yield of 2000million tons (Paudel, 2007). The bamboo culm is a cylindrical shell divided by transversal diaphragms at the nodes. Bamboo is an orthotropic material with high strength along and low strength transversal to its fibres (Jain, 1992).

Bamboo can be considered to be a structural material, consisting of long and aligned cellulose fibres immersed in a ligneous matrix. The cross-section of a bamboo culm shows that the distribution of fibres varies across the section, increasing in density towards the outer surface of the culm (Ghavami, 2007). This responds to the natural stress state in its natural environment where plants as high as 30m have to resist large wind shears. Bamboo can be considered as a functionally graded material.

Bamboo used at the growth source is a carbon neutral material. In comparison, the production of 1 ton of steel generates up to 2 tons of CO_2, while bamboo absorbs CO_2 and releases oxygen (Janssen, 1981). Bamboo has extremely high strength to weight ratios and can attain tensile capacities of up to 370MPa (average values of 170MPa was measured by Ghavami where average values are the mean of the top, middle and base of the plant).

Bamboo is extremely fast growing and most species reach maturity in 3-7 years. After harvesting the bamboo naturally re-grows from the extensive root matrix (if left to its own devices bamboo dies and re-grows over a 10 year period but stands of over 50years have been noted). Use of selective harvesting avoids damage to the carbon stock and provides constant sequestration unlike timber that is heavily impacted by crop rotation.

As a single material it has strength, flexibility and versatility that makes it a suitable material for lightweight structures.

Laminated Bamboo

The culms are naturally hollow in the centre and therefore we have only the wall thickness of the stalk to work with. The wall at the base can be more than 25mm thick but will taper over the length of the stalk.

As shown in the figure to the right, the stalk is initially split lengthwise into strips. These strips are then boiled in a bath of boric acid and lime solution. The purpose of this bath is to extract

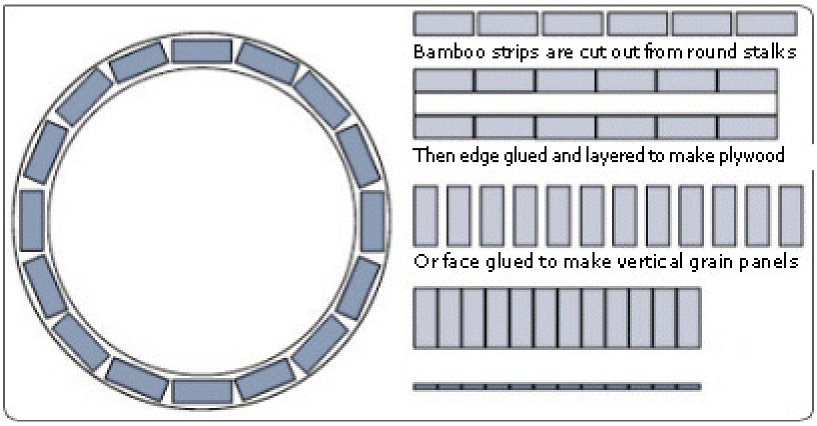


Figure 5 Bamboo for laminated products

the starch that attracts termites and powder post beetles. Boric acid and lime are a natural non-toxic repellent, used to insure that our products will come to you pest free and will continue to be so throughout the duration of their product life.

The strips are kiln dried and sanded to a smooth surface for laminating. They are then laminated edge to edge to create a single-ply panel. These panels are then laminated again to each other to create multi-ply bamboo plywood (Rittironk, 2007). Or they may be face glued to make vertical grain panels.

With modern glues, laminated bamboo is extremely strong and durable and can replace any of the functions of wood laminates. Glues with extremely low phenol-formaldehyde content should be used. Avoid urea based formaldehyde glues which have high VOC contents. Dynea, in cooperation with the Dresden Institute for Wood Technology (IHD) have developed a protein modified Phenol-Formaldehyde (pPF) resin, which is part of Dynea's AsWood™ resins product family.

Figure 6 Bamboo laminate

The wood-based bonded boards produced with this new technology exhibit formaldehyde emission levels as low as those found in solid, untreated wood. In addition to achieving these ground-breaking, extremely low emission levels, the AsWood™ resin also contributes to superior surface quality in the final product.

Bending strength of laminated bamboo has been tested and consistently achieves 82MPa, with good compressive and tensile strength capacities.

Table 1: Material Properties Comparison Table

Material	Steel	Aluminium	Glass	Timber	Bamboo	Laminated Bamboo
Density kg/m^3	7,850	2,700	2,500	650	600	780
Strength / weight	32	78	28	61	100	105
Modulus, E	200,000	70,000	69,000	11,000	19,000	19,000
Embodied Energy (MJ/kg)	25.4	154	28	7.8 [12]*	7	12
Embodied carbon (kgCO_2/kg)	1.83	8.21	1.27	0.50 [0.65]*	0.40	0.65
Expected life (years)	>50	>50	>50	Up to 25	Up to 25	Up to 25

Notes – * figure show in brackets are for Laminated timber products – the results of laminated timber and laminated bamboo are similar. Bamboo also yields greater biomass and sequesters more per Ha than similarly grown indigenous timbers

Applications of Bamboo in facades:

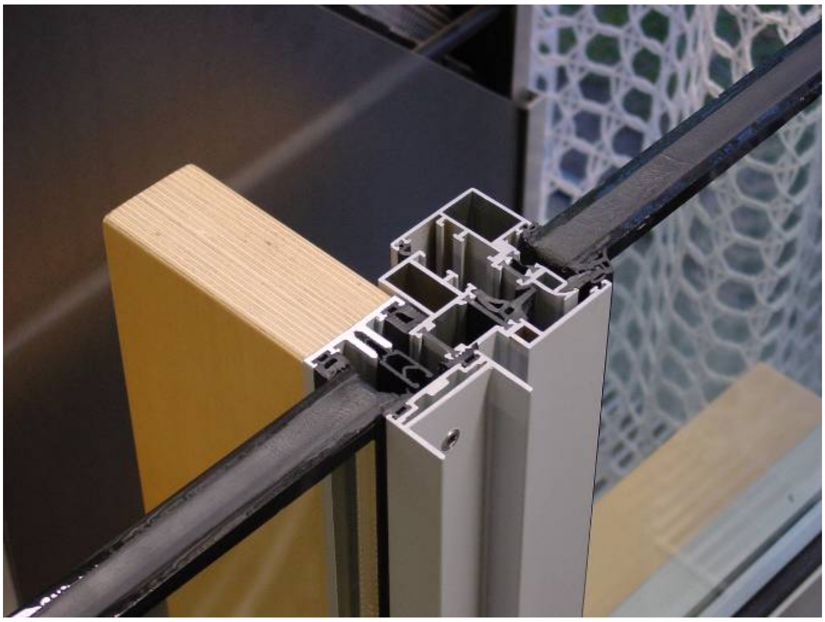


Figure 7 prototype curtainwall with laminated stiffener

Consider a lightweight facade using aluminium glazing pocket with strength augmentation derived from laminated bamboo stiffener.

In order to meet the high performance requirement of weather and air ingress the bamboo element becomes a stiffening element for an interlocking glazing system while the aluminium is retained in small quantities to maintain the weathering resistance.

Traditionally aluminium is used for curtainwall because of the high strength to weight ratios, the ease of extruding the desired shapes for interlocking systems and the extremely good weathering resistance.

The bamboo provides a good alternative for achieving stiffness so as to achieve the required strength and deflection limitation. The higher strength to weight ratios provides for a stiff panel which improves air infiltration and weather resistance.

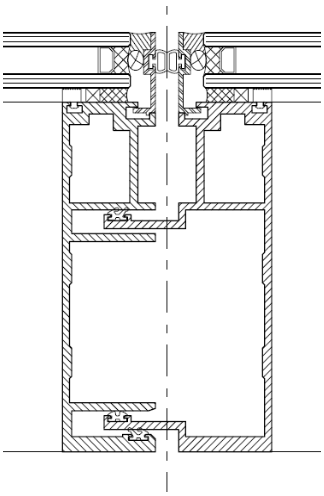
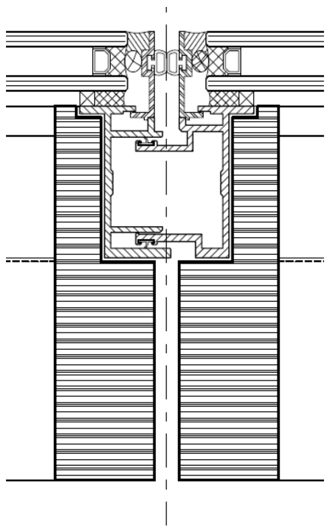
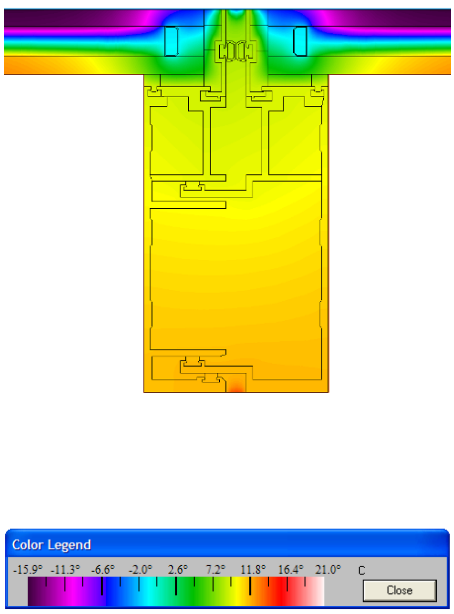
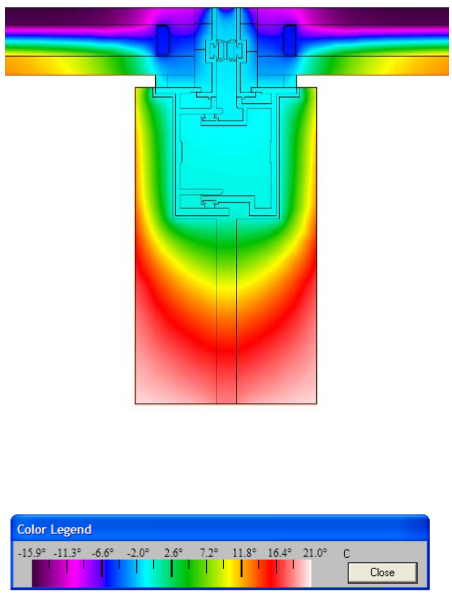
In preparing this paper we compared a typical all aluminium curtainwall with the laminate augment stiffener system, for assessment we used the following criteria;

- Analysis criteria – deflection and strength criteria common for handling during construction and in service loads(span on 290 at serviceability wind loads, no permanent deformation under any load)
- Panel size 1500mm wide by 3800mm high
- Vision Glass 2800mm high, with high performing insulated glass U-value of 1.6W/m^{2}K
- Solid spandrel 1000mm high with centre on panel U value0.5W/m^{2}K

The main advantages of cladding the aluminium frame with laminate bamboo mullions include, the table below summarise the calculated figures;

- Enhanced Thermal performance –
  - Impact on energy -reduced heat flow over the largest metal surface result in overall reduction of transmitted heat loss/ gain, overall reduction in energy through the entire cladding systems (25% improvement)
  - Impact on Indoor Environmental Quality – reduced risk of condensation improves air quality and avoid mould and degradation, improved thermal comfort adjacent to the facades due to reduced surface temperatures
- Natural timber appearance improved IEQ to well being of natural materials - More natural fee with warmer tones
- Opportunity to offset greenhouse gas production through sequestered content
- 60 % reduction in embodied energy for the façade
- Similar overall panel weight – due to strategic use of material
- Maintained modular and prefabricate construction
- similar ability for recycled content by mass

Table 2: Curtain Wall Mullions

	Traditional aluminium framed curtainwall mullion	Laminated bamboo framed curtainwall mullion
Mass Aluminium (kg/m^2)	**5.7**	**2**
Mass Timber (kg/m^2)	**-**	**5**
Mullion U-value (W/m^2K)	**10.3**	**5.1**
Panel U-value (W/m^2K)	**2.38**	**1.77**
Embodied carbon of mullions ($kgCO_2/m^2$) (Hammond 2008)	**46.7**	**19.3**
Embodied energy of mullions (MJ/m^2) (Hammond 2008)	**878**	**314**
Sketch of mullion		
Therm output showing isotherm gradients		

Feature walls (and Roofs)

Typically a glass feature façade to the entry of a building or the roof enclosing an occupied area are designed such that they "make a statement".

The feature façade is defined by aesthetic design where the designers are trying to achieve either a wow factor at the entry or space. This has been achieved through minimal visible structure, large spanning glass, large surfaces. In some instance warmth and sustainable story has been added through the use of structural timber or even steel frames clad in timber. The selection of the timber needs to follow a sustainable certification path or large laminated elements.

Figure 8 KENS Glass wall - glass with 14m horizontal tension cable

Figure 9 Lightweight Glazed Roof British Museum

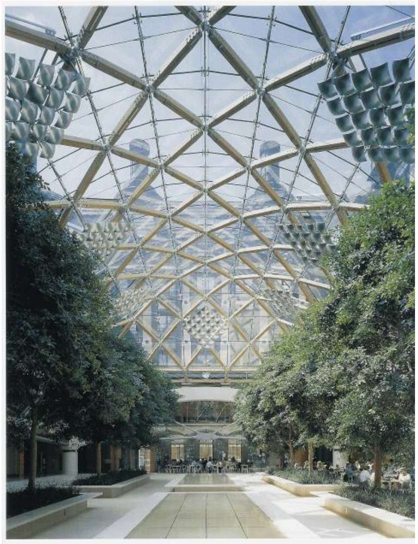


Figure 10 Lightweight Glazed Roof - timber structure Portcullis House

Instead of adopting large format monolithic glass for a feature wall a more efficient and sustainable methodology may be to accept a small glazed elements with a grillage of support structure as is used in the grid shell structures used for these roofs. The grillage may fulfil multiple roles of both structural support and provide shading and interest.

The smaller prefabricated and repeating element provides both interest and education of sustainable issues such as reuse, lifecycle, carbon cycle, resource efficiency while provide a natural scale and reinforcing the necessity of human contact with nature.

It is first worth reviewing the sustainable efficiency of the various materials used in large scale walls before looking at the marriage of the small element (curtainwall) to the large feature wall.

We completed a similar comparative embodied energy study to the curtainwall above by comparing timber, steel, aluminium, bamboo for straight span of 12 – 15m at 2m spacing and one of a diagrid on 2m square.

Again the elements were designed and analysed so as to achieve a similar stiffness to meet performance requirement for glass walls in service, with a maximum deflection set at 50mm. We have assumed that parity in performance of secondary elements such as gaskets, glazing etc and support structure so that the feature structure alone is compared.

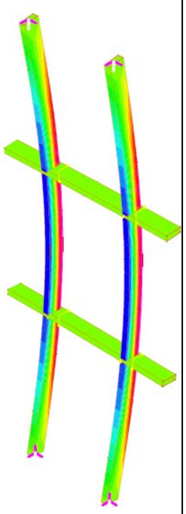
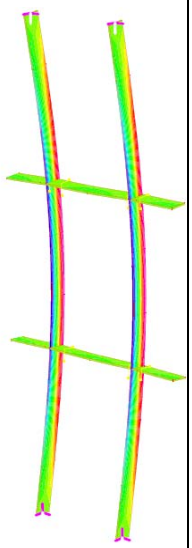
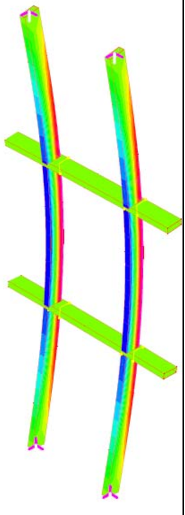
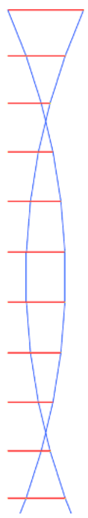
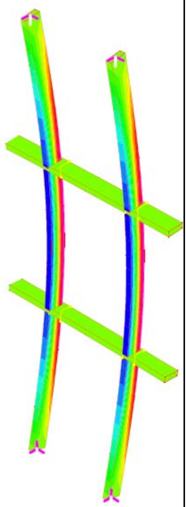
In large span walls deflection criteria can be relaxed compared to curtainwall deflection provided that the glazing does not take on secondary stress due to applied geometric constraints, fail in service or result in permanent deformation.

Lightweight post tensioned feature walls that rely on "strengthened" primary structure, such as the KENS wall above need to include the impact of the additional support structure in the embodied energy calculation.

A summary of results are shown in Table 3 below. From a sustainable point of view the glass fin option and Laminated bamboo perform in a similar way, however the calculation does not account for sequestering carbon. The aluminium having the lowest mass but highest embodied energy.

While a paired cable tensioned structure resulted in similar embodied results as the glass fin and laminate beam. When tested the KENS project (picture above) the embodied energy in the reinforcing structure resulted in more than 50 fold increase over the cable alone resulting in a embodied energy 5 times greater than the aluminium alone solution. Not a very environmental "lightweight" solution after all.

Table 3: Entrance Facade Systems

	Aluminium Box mullion	Glass fin mullion	Steel box mullion	Steel reverse tension cable	Laminated bamboo mullion
Size	415x150x10 RHS	420x36 fin	270x150x10 RHS	2x 16mm dia rods 1000mm deep profile	400x150 solid
Mass (kg/m^2)	13.1	15.7	26.2	15.2	19.5
Embodied carbon of mullions ($kgCO_2/m^2$)	107.6	19.9	49.2	27.3	12.9
Embodied energy of mullions (MJ/m^2)	2009	441	664	373.4	234
Sketch of Entrance Facade					
Notes	Extrusion size not practical and will be manufactured from several pieces, the embodied energy is poor.	Common detail with glass structurally bonded to glass fin or fixed via patch fittings	Welded-up steel RHS with aluminium flat fixed to face for bonding on face glass – common detail	The impact of additional reinforcing structure is included in the calculations	Alternative to use solid timber member with aluminium flat fixed to face for bonding on face glass.

Concept for bringing the two ideas together

The modular facade pictured (right) is a proposal that incorporates the benefits of both the curtainwall small repeatable façade with the large span feature structure.

The large span structure is developed from a single repeatable elements fabricated from laminate bamboo elements from 2 repeatable shapes. It deals with varying and larger spans by the introduction of secondary layers which can be introduced behind the primary layer which carries the glazing elements.

Design of the modular systems reduces the size of the glazing to small manageable and safely handled elements less than half the size and weight of standard curtainwall panels, their connection to the primary grid is via a node which is integrated into and sets the geometry for the support structure.

The primary and secondary layers are constructed from a single shape comprised of 3 pieces (of 2 shapes) and joined by cast steel nodes. Each element is typically 300mm by 20mm formed plate.

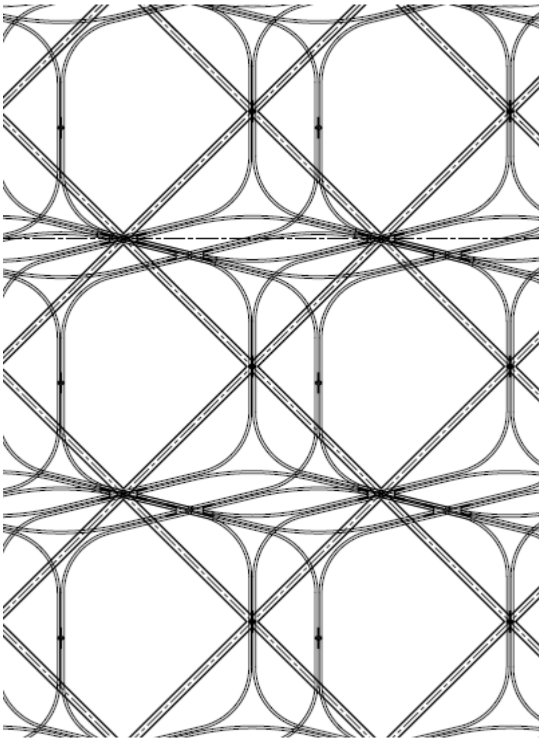
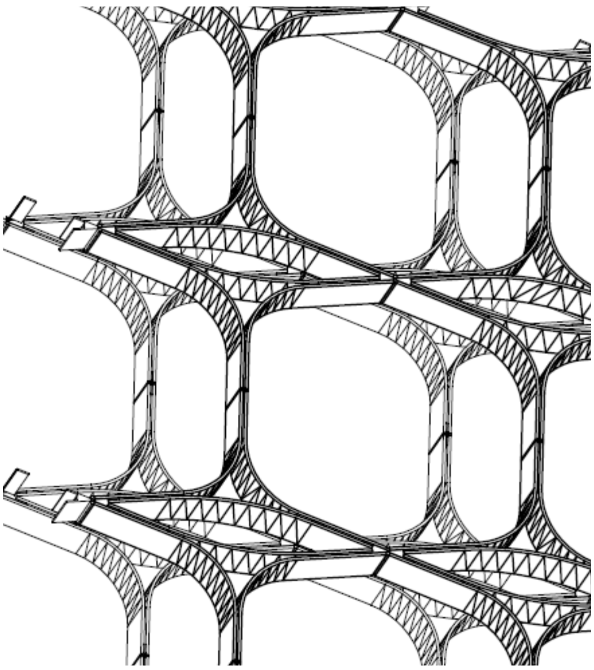


Figure 11 Concept for Repeatable Modular facade



By using the interconnect grillage and constructing the feature wall from thin laminate bamboo results in an overall weight and embodied energy similar to that of the single laminate beam. It has advantage of small modular repeatable elements that, depending on orientation, can acts as sunshades as well as structure creating a truly integrated lightweight structure.

Conclusions

The use of alternate and sustainable materials in building facades can result in truly sustainable lightweight facades that have greater sustainable performance in all areas over traditional materials.

The 2 systems typologies reviewed in this paper are employed in every building today and this paper demonstrates the versatility that the use of bamboo could bring to future buildings.

Greater efficiency in thermal performance, improved health and Indoor Environmental Quality, reduced footprint through embodied energy and greater opportunity to sequester carbon, better whole of life materials that can be recycled that produce a lightweight, modular, repeatable and improved method of construction.

References

1. Prof. G Hammond & C Jones, 2008, University of Bath, Inventory of Carbon & Energy (ICE) Version 1.6a
2. Jain S & Kumar R, 1992, Mechanical behaviour of bamboo and bamboo composite, Journal of Materials Science 27 (1992) 4598-4604
3. Ghavami K, 2007, Bamboo: Low cost and energy saving construction materials, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
4. Paudel S K, 2007, Engineered Bamboo as a Building Material, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
5. Xiao Y, Shan B, Chen G, Zhou Q & She L Y, 2007, Development of a new type of Glulam – GluBam, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
6. Rittironk S & Elnieiri M, 2007, Investigating laminated bamboo lumber as an alternate to wood lumber in residential construction in the United States, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
7. Correal J & Lopez L, 2007, Mechanical properties of Colombian glued laminated lumber, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
8. Guan M J& Zhu E C, 2007, Flexural properties of bamboo sliver laminated lumber under different hygrothermal conditions, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
9. Liu W Q, Yang H F, Dong F Q & Jiang D M, 2007, Experimental study on flexural behaviour of glulam and laminated veneer lumber beams, Proceedings of first international conference on modern bamboo structures (ICBS-2007), Changsha, China, 28–30 October 2007
10. Janssen J, 1981 Bamboo in building structures, Thesis Eindhoven Technical University
11. http://www.greenspec.co.uk/html/materials/embodied_energy.html