ENGINEERED BAMBOO FOR SUSTAINABLE CONSTRUCTION CONFERENCE
Virtual / March 17-19, 2022
FOLLOWUP TO PARTICIPANTS QUESTIONS

Questions for speakers and panel

Contact List, see Addendum

1. MATERIAL SELECTION AND SUPPLY

Topic: Fibre quality (species, growing location)

(Q for Ramage) Which species of bamboo are best suited for structural applications?

Reply RAMAGE: There are about eight species of giant grass that are suited for structural applications, but we can distinguish between those used for structural applications without processing, which are part of vernacular traditions around the world, and those used for structural applications in engineered bamboo products, for which Moso (*Phyllostachys pubescens*), Guadua (*Guadua angustifolia Kunth*), Tre Gai (*Bambusa blumeana*), *Dendrocalmus asper*, and a few others are most common.

Reply LUCAS: Depending on one's locality, using what is local makes sense. If there is no bamboo in the locale, then it depends on the application. Many species can be used split and made into panels or composites. Species with thick walls and great strength can be used as load-bearing. If durability is an issue, it can be mitigated by harvesting at the most appropriate age and preserved with drying, borax, etc.

Reply Harries: Most species having suitable dimensions can be appropriate for structural applications. ISO 22156 directs the user to species having D > 50 mm and D/t > 10.

(Q for Dai) Are all species of bamboo appropriate in construction system

Reply DAI: No. There are over 1300 species of various bamboo around the world. There are probably fewer than handful of species that are most suitable for construction. The main criteria here is the size of bamboo culm for large scale commercial manufacturing.

Reply LUCAS: In 1966, US Botanist F.A. McClure selected his top Elite Species, and many of those still hold true for today. Missing from McClure's list was Moso <*Phyllostachys pubescens syn. edulis*> and *Dendrocalamus asper.*

(Q for Ramage) Are *Dendrocalamus asper* (Indonesia) and *Guadua angustifolia* (Colombia) stronger than Chinese Moso and hence, better suited in structural applications?

Reply RAMAGE: They are not particularly better suited to structural applications. There is variation within species and among species, and strength isn't always the best predictor of structural

performance. Stiffness is often a better indicator, and raw stiffness is perhaps less important than the engineered component created during processing.

Reply LUCAS: They are not stronger per se. “Asper” and “Guadua” are from distinctly different growing regions and have different characteristics compared to Moso. Moso cannot be grown in arid climates: Asper can. Guadua is native to South America, so it makes sense to use Guadua where it is grown extensively.

Reply HARRIES: This is an ill-formed question. In timber design, we do not ask which is stronger, pine or oak, we are able to use both with there own limitations. Indeed, structural steel comes in grades ranging from about 250 MPa to over 700 MPa. Provided one knows the strength (and stiffness), one can use the material.

Reply HINKLE: In our applied work we find stiffness (not strength) to be the limiting mechanical property when value and load optimizing a structural design.

See this link: https://www.matec-conferences.org/articles/matecconf/abs/2017/52/matecconf_eacef2017_01024/matecconf_eacef2017_01024.html

(Q for Panel) Compared to Moso (a temperate bamboo), Dendrocalamus (tropical bamboo) is harder and has thicker culm walls. Is this an advantage in structural applications?

Reply HINKLE: To complete a species comparison one would plot strength v. stiffness for various species and would view the continuum. In our practical work we find Moso having high strength (and critically hardness as seen in its Janka rating and use in flooring) but lower stiffness than most framing timber (wood) and tropical timber bamboos.

(Q for Van der Lugt) *Bambusa vulgaris* (green) is one of the strongest bamboo species, perhaps superior to D. asper which also have pan global distribution status. Why is utilization of this species not considered?

Reply VAN DER LUGT: I am not aware that Vulgaris is known as one of the strongest bamboo species, I believe it is often used for pulp/paper production. If with utilization is meant industrial utilization e.g. for engineered bamboo products, this often depends on many different factors such as the processability (e.g. straight culms and fibers enabling industrial processing), location (forests / plantations near roads, harbours, etc for distribution to bamboo processing industry), suitability (sufficient strength, durability, hardness etc for engineered bamboo applications), availability (sufficient feedstock to run a manufacturing facility), knowledge / experience of architects with this species, legislation / available building norms and codes, and many other factors.

Reply LUCAS: I have seen vulgaris typically used for short-term needs. It is also used to harvest leaf-extracts for the cosmetic/nutraceutical industry. Salt-water preservation methods for culms are used along the seacoasts where you see most utilized. I have met some builders who do prefer it.

Reply HARRIES: It is in many regions where it is endemic. One issue with *B. vulgaris* is that it is often not terribly straight.

See this link: https://www.scielo.br/j/eagri/a/9SLJM7VHyYdzyF7tVK4gynr/abstract/?lang=en

(Q for Panel) What are the advantages of using *Dendrocalamus giganteus* bamboo ?

Reply LUCAS: D. giganteus is the largest stature bamboo in the world but still has limited regional distribution since the seeds are not frequently available. It is still to be determined where it can be grown successfully however it is looking promising in south Florida and is now being cultivated more outside its native region.

Reply HINKLE: As mentioned variously above, size and mechanical properties (strength, stiffness, hardness) are poorly correlated.

See this link: https://www.sciencedirect.com/science/article/abs/pii/S0950061816315549

(Q for Ramage) How can bamboo quality be standardized when it comes from different growing regions?

Reply RAMAGE: The standardisation comes in the processing, and in the specification of the final end products, not in the raw materials. A range of bamboo quality can be used to produce a range of standardised products – we have this system already in wood products – C16 and C14 designations for softwood properties, for example.

Reply HARRIES: Grading. See ISO 19624

See this link: https://www.inbar.int/first-international-standard-on-engineered-bamboo/

(Q for Davies) Is the yield of a bamboo forest per year per hectare about the same as that of a wood forest?

Reply DAVIES: I can't answer this specifically as I have not seen (or looked for yet) a study directly reporting this, but it is a good question. The growing regions vary widely (both for bamboo and for timber). This question should be answered based upon a growing region where either bamboo or timber are both candidates (such as the US South East). I fully expect the bamboo forest to offer a much higher sustained yield with time, but I have not seen the data to support that statement.

Reply HINKLE: We studied this in the literature and then we modeled this in our publication "Carbon Farming With Timber Bamboo". We concluded that at the extremes mature stands of timber hold more above ground biomass than mature stands of timber bamboos. However, timber bamboo, because once cut it regrows in the next growing season, can be more productive assuming the partial harvesting and removal of culms.

Topic: Source of Material (supply chain, quality, cost)

(Q for Ramage) Where does your raw material come from? Who produces your materials? And what do you think will be the level of demand by 2025?

Reply RAMAGE: We tend to use material that is grown and processed in China. Demand in 2025 is probably going to be incrementally more than in 2022; I don't expect exponential growth in that short a time.

See link: https://www.inbar.int/resources/inbar_publications/trade-overview-2018-bamboo-and-rattan-commodities-in-the-international-market/

(Q for Ramage) How does engineered bamboo compare to EWP in the UK with regard to price point, attributes and performance?

Reply RAMAGE: In the UK, engineered bamboo is still a nascent industry so it is generally more expensive than equivalent timber. The attributes are highly dependent on the specification; performance at the moment is typically similar, as the stiffnesses and cross-section shapes are similar. With innovation on cross-sections, performance could increase.

(Q for Davies) Is it still 'sustainable construction' to ship bamboo a long way from where it is grown to where it is sold and used? What impact does this additional transportation have on the embodied carbon emission of the construction material?

Reply DAVIES: Generally, yes, as long as the LCA takes this into account. Most materials are globally traded and transported commodities, including steel. Bamboo is lighter than steel, and its growth locks carbon into the material. Of course, this is on a case-by-case basis, but keep in mind that timber is currently a globally sourced and shipped material for construction today already. For a recent mass timber project in Atlanta, the glu-lam beams came from an Austria fabricator, after being cut from a forest location in East/Central Europe. For that same project, the mass timber floor planks came from British Columbia, Canada, shipped via truck to Atlanta. In a study of the shipping impacts from that project, the shipping was about a 15% embodied carbon impact to the structural frame numbers, effectively negating the "carbon negative" savings from sourcing from a sustainable forestry operation, as it is reported within the WBLCA tools in use today. I suspect the bamboo shipping impacts (especially if they are mostly a ship transport which is fairly carbon efficient) will be similar to those already being experienced with most mass timber use within the US today. Should we be working to do better than the above? yes. But this is the reality of what is happening currently.

Reply LUCAS: I believe Pablo van der Lugt replied to this question. The answer lies in the management of the plantation, the annual harvest cycle <it is regenerative>, and its LCA.

See link: https://worldbamboo.net/wbcix/presentation/Van%20der%20Lugt,%20Pablo.pdf

Reply HARRIES: Bamboo in culm form is very inefficient to ship. In engineered form, it is about the same as wood products of similar density. The work of Edwin Zea has demonstrated some of these [in]efficiencies.

(Q for Chui) What kind of bamboo can we use for lamination?

Reply CHUI: Currently the engineered bamboo composites are made by gluing smaller strips or strands together. Therefore, I don't see any problem using sympodial species if the mechanical properties of the strips or strands are adequate.

(Q for Chui) In Indonesia, our bamboo is sympodial <clumping> species and not monopodial <running>, would that effect lamination process and performance?

Reply CHUI: No.

(Q for Davies) Which country is the powerhouse for bamboo commodity products and which country is the powerhouse for engineered bamboo structural products?

Reply DAVIES: Bamboo is a widely grown material. To my knowledge China and India hold some of the largest bamboo sourcing opportunities that are available today. For material coming to the US, we are seeing sourcing from Central and South America as most premiant, but the entire industry is in an infancy of where it can go. I will defer to Hal Hinkle at Bamcore as a better commentator on bamboo sourcing opportunities as they exist.

For engineered bamboo structural products, I continue to always be impressed with what I see coming from people like Pablo van der Lugt. Rather than a single center of design excellence, though, what I see today are pockets of excellence, typically centered around a few individuals, scattered around the world. Bamcore has been doing some impressive work, not on specialty show pieces in bamboo, but on fiber optimized mass plywood production processes. That simplified but optimized mass production is what needs to be happening to really advance the industry the most.

Reply LUCAS: China. However, countries like Vietnam, Indonesia, Ethiopia, Philippines, and India are all making significant headway. Hilti Foundation's Base/Bahay in the Philippines is doing great work with affordable housing units.

(Q for Sands) Are the bamboo timbers and round bamboo used in your project manufactured by Rizome or other sources?

Reply SANDS: The round bamboo timbers are manufactured by Bamboo Living and the dimensional bamboo materials by both Bamboo Living and Rizome.

(Q for van der Lugt) I'd like to know the price of bamboo timbers used in your company? Compared with wood timber?

Reply VAN DER LUGT: This really depends on which product you are referring to as the company MOSO has many different products for outdoor and indoor use, made via different manufacturing processes: https://www.moso-bamboo.com/bamboo/how-bamboo-products-are-made/

As a very rough rule of thumb you can say that the indoor flooring products are in the same price range as a good quality FSC certified oak floor and outdoor products are slightly less expensive than the best quality FSC certified tropical hardwood species. However, recently wood prices increased significantly in Europe, therefore this situation might change and engineered bamboo becomes even more competitive in pricing.

Topic: Factors driving supply (monetized demand for bamboo, efficient supply chains)

(Q for Sands) How are you addressing supply country diversification for risk mitigation with Rizome? And which communities and areas in the Philippines are you working with?

Reply SANDS: We are currently working in the Philippines, USA, and India but will be adding projects in other countries. **And which communities and areas in the Philippines are you working with?** Mindanao

(Q for Hinkle/Hammann) How does Africa position itself to make use of timber bamboo as a primary building material in the face of available low fibre indigenous species like *Bambusa vulgaris* and low prevailing building technologies?

Reply HAMMANN: Hal Hinkle will need to answer this one. Lamboo does not work with any sources out of Africa at this time.

Reply HINKLE: The prior generation planting of non-indigenous bamboos in Africa might not serve well for present and future demand of engineered products. It seems to have been driven more by available land needing restoration (a different valuable purpose). However, recently commercially competent processes are establishing themselves in more politically stable locations in west Africa and South Africa. We have high expectation but transport, infrastructure and political stability will be critical to achieve commercialization.

(Q for Panel) How do you motivate farmers to plant bamboo? How can carbon credits be transferred to those farmers who do the best job?

Reply LUCAS: There is little reason for farmers to plant bamboo unless there is a nearby processing facility manufacturing a product in demand. Harvesting, drying, preserving, storage, and transportation costs all require capital and a buyer who needs bamboo on a regular basis. Plantation and market feasibility studies are vitally important before any planting begins.

Reply HINKLE: Carbon credits for bamboo and harvested/engineered bamboo products is complicated. There are three opportunities: (1) incremental standing biomass, (2) harvest carbon stored durably and (3) substitution benefits for the reduction in the use of other higher embodied carbon products when engineered bamboo is substituted. Only (1) would flow to farmers. If you are not aware: Verra has certified or will have certified at least three large planting of timber bamboo, one in Nicaragua and two in the Philippines. Unfortunately, the value of the (1) carbon credits is quite low (~$10/tonne) and large

scale is required. Therefore, the smaller farmer is not likely to see subsidizing carbon credits for planting timber bamboo in the near future.

(Q for Panel) Most of the conversations about the potential markets for engineered bamboo products focus on developed economies. What potential is there for the manufacture and sale of laminated engineered bamboo products in developing countries which have large quantities of timber bamboo? Latin America, South Asia etc.?

Reply DAI: There is potential in both developed and developing economies. Engineered bamboo is typically produced in the countries where it is grown; Some of the processing generally has to take place while the material is green – i.e. before it dries. Those who buy it can come from anywhere in the world.

Reply LUCAS: I don't want to speak to potentials for manufactured products in developing countries, but I do want to point out that there is not a large quantity of timber bamboo available. Most bamboos found around the world are not on managed plantations. Most bamboo is growing in native forests and cannot simply be "sourced" and cut down. We should not repeat the mistakes made re: other tropical species that were exploited without concern for the local ecologies and communities dependent on them. This is why I am a strong advocate for creating bamboo plantations to meet the growing demand of bamboo products in both developing and developed economies.

Reply HARRIES. There are many projects worldwide attempting to valorise local bamboo products. I am personally involved in two such endeavors; both in developing economies.

2. CONVERSION

Topic: Methods, efficiency

(Q for Ramage) Can you elaborate on the part where you mentioned something along the lines, "that work is needed for engineered bamboo to be turned back to the cylindrical culm shape". Why would that be important?

Reply RAMAGE: Bamboo is typically significantly stronger than wood, especially softwood widely used in construction. But it isn't much stiffer. Many structural engineering designs are stiffness-limited. By using efficient sections, i.e., a hollow cylinder, we can take advantage of the higher natural strength of bamboo.

(Q for Ramage) What is the recovery rate of processing bamboo into engineered wood products?
Reply RAMAGE: It depends on the product, but typically 80% can end up in scrimber, 30% in laminated bamboo.
See link: *Engineered bamboo: state of the art Sharma, Gatoo, Bock, Mulligan and Ramage*

(Q for Chui) For getting more straight structures, we are avoiding the outer layers of the culm which contains very high percentage of lignocellulose. Is there any method available for making use of this portions too?

Reply CHUI: I believe Parallel Strand Bamboo could be the product to consider if this portion is to be included. Straight edge strands are not essential for PSB.

(Q for Sands) What is the culm to product conversion rate and % of fossil adhesives in engineered bamboo?

Reply SANDS: Around 50% conversion rate. Percent of fossil adhesive is from 2-10% based on the specific product. We <Rizome> plan on using biobased adhesives wherever possible as those get further developed.

(Q for Dai) What are your views regarding the sourcing side of bamboo and how does that it relates to what we can manufacture? For example, strand woven products allow us to use a higher percentage of the culm.

Reply Dai: Fresh bamboo cannot be stored like wood and the hollow nature of bamboo requires more manual processes than wood products. For these reasons, bamboo should be best processed or pre-processed close to the source. It would be better to create more value-added products or intermediate products like strand woven which can be shipped and further processed for broad market applications.

(Q for Harries) Are acoustic tools suitable for NDT testing and grading of culms before conversion?

Reply HARRIES: Possibly. Bamboo culms represent a complex geometry and most acoustic tools rely on some form of a priori wave path or wave guide. This is likely a promising field of study, but for the moment, I would not believe anyone who said that they could grade bamboo in this manner.

(Q for Dai) Six days or so for drying bamboo is quite long. Any solutions to speeding up this process?

Reply DAI: It is very long. We are studying the drying mechanisms which could lead to potential solutions. For a start, bamboo mills need to have better control on the temperature and humidity conditions like wood kilns do.

(Q for Mei) What is the percentage recovery using flattening technology?

Reply MEI: I suppose the term "technology-specific carbon transfer ratio" in my presentation is the "percentage recovery" raised in the question. We have built up relationship between bamboo culm diameter and carbon transfer ratio for the flattening technology which is Y=3.064x+27.369 (where y is the carbon transfer ratio, and x is the bamboo culm diameter). For bamboo culms with diameters of 10 cm and 20 cm, we can roughly get their carbon transfer ratio of 58.0% and 88.6%, respectively.

(Rodriguez) What are the investment costs of a facility to produce pre-fab housing components?

Reply RODRIGUEZ: A Kuna factory with 2500 sq.ft of assembly space and 3500 sq.ft raw bamboo storage space will cost $35,000 for a bamboo building and $12,000 for all machinery, it excludes foundations and electric wiring.

(Q for Panel) Has there been any investigation or application on using the denser outer fibers of the bamboo culm? It is my understanding that this is sanded off due to the lack of adhesion. Is this a missed opportunity?

Reply HAMMANN: The outer layer of the bamboo unfortunately does not function well within the manufacturing process of creating the slats required to glue up making the final product. Due to its non-adhering surface, it is too difficult to glue materials together as the adhesive will not stick to it. Removing the outer layer is the best solution at this time when making laminated engineered bamboo.

(Q for Panel) Can anyone comment about waste from culm conversion and glue?

Reply HAMMANN: All waste generated in the engineered bamboo process is used or recycled into other by-products therefore, all the bamboo is utilized. Approximately 20 kg of adhesive is used in 1 cubic meter of laminated engineered bamboo. Once dry and residual adhesive is sanded on the surface, 0.012 kg of adhesive will remain in 1 kg of laminated engineered bamboo.

(Q for Panel) To produce Strand-woven laminated bamboo, should we put same species of bamboo or do we put random bamboo, and does it make an impact on its engineered bamboo?

Reply HAMMANN: If you combine various species of bamboo which have different mechanical properties, the finished product will more than likely have different mechanical values than an engineered bamboo using the same species. The important decision to note; does the product using mixed bamboo species meet the mechanical property requirements for the application the final product will be utilized in.

(Q for Panel) Can post-harvest treatment affect the end-product (engineered bamboo)?

Reply HARRIES: Of course, it can. There are many studies addressing the effects of many different treatments.

Topic: Adhesives (performance, sustainability aspects)

(Ramage) What kind of glue is used for your engineered bamboo building materials?

Reply RAMAGE: Typically, polyurethane glues that are similar to those used in cross laminated timber but formulated for the lower moisture content of bamboo. There are some soy-based adhesives in use on engineered bamboo panels.

(Q for Chui) Are there environmentally friendly adhesives?

Reply CHUI: Yes, there are bio-based adhesives, i.e., soy, lignin, etc., that can be used. However, their durability performance may not meet the requirements of adhesives that are intended for structural applications. Typically, qualified structural adhesives are subjected to harsh accelerated moisture cycling regime during qualification and quality control.

Reply HARRIES: Yes, there are but they tend to be cost-prohibitive at the moment and, as a result, see little attention.

(Q for Van der Lugt) Gluing small pieces of bamboo takes more adhesive than gluing large pieces of wood. What is being done to reduce the impact of adhesive embodied carbon? What are the cost considerations?

Reply VAN DER LUGT: That is correct, depending on the product, the glue content (dry weight) can vary between 2-10% (laminated products vs thermally modified high Density bamboo), which in general is higher compared to engineered / laminated wood products (1-5% depending on the product). Usually, the same kinds of synthetic glues are used for engineered bamboo products compared to engineered wood products (for indoor use MUF, for outdoor use PF glue). Based on the latest EPDs by MOSO <company> (2022) https://www.moso-bamboo.com/lca/ we can confirm that the glue has a considerable impact on the total carbon footprint, depending on the product accounting for about 10-40% of the carbon footprint.

With several partners MOSO <company> is investigating the use of a biobased alternative for the PF glue and performing testing on this in production facilities. This takes a lot of time as it is very difficult to find a cost-effective alternative (current biobased adhesives are up tot 2-3 times more expensive) for current adhesives that fit existing production parameters while meeting the high technical performance criteria that we put on our products, MOSO <company> does not want to compromise on quality whatsoever and acknowledges that a highly durable product is also part of the sustainability value.

(Q for Dai) Could the outer surface of bamboo be lightly sandblasted with a very fine grain sand to allow a textured surface for the epoxy to bond?

Reply DAI: We thought about this idea and found some work done already in Korea. It seems like a good idea with potentially minimal removal of the waxy layer while preserving the outer wall fibers.

Reply HARRIES: There are studies that have done this. Obviously, it becomes another step in manufacture with its associated costs (both monetary and otherwise).

(Q for Dai) How much adhesive is applied to make each type of product (Laminated bamboo, Laminated flatten bamboo, Bamboo Scrimber, Bamboo laminated veneer lumber)?

Reply DAI: My guess is that 3-5% on oven dry weight basis for laminated bamboo, 4-7% for laminated flatten bamboo, 12-15% for bamboo scrimber and 10-13% for bamboo laminated veneer lumber.

(Q for Dai) With respect to bamboo-wood hybrid composites, is there any significant difference in bonding properties of different layers of bamboo i.e., inner, middle or outer lamella bonded with wood surface?

Reply DAI: While there is significant difference between the bond wood-resin and bamboo-resin interfaces, the differences between inner and outer lamella are insignificant.

(Q for Dai) Which resin is used for bamboo pipes?

Reply DAI: Modified urea formaldehyde resin mixed with substantial amounts of bio-fillers.

Reply HARRIES: One must consider that in pipe applications, the performance requirements may be quite different requiring specialized resin systems.

(Q for Dai) Would bamboo scrimber produced with a biodegradable resin be the dream product that could replace conventional timber?

Reply DAI: Not in my opinion. This is because the current bamboo scrimber is structurally and process-wise far from optimum compared with wood composites, leading to high resin and energy consumptions. More innovations are needed to design better products and processes.

(Q for Gutierrez) For the elevated temperature compressive tests, was the same adhesive used for all samples and what was the adhesive?

Reply GUTIERREZ: During my PhD research, I worked with laminated bamboo made with three different types of glue. Polyurethane, Resorcinol Formaldehyde, and Phenol Resorcinol Formaldehyde. Few tests were conducted with Polyurethane samples, as they did not perform well, and they were not easy to access during my research. Most of the studies were worked with Phenol Resorcinol Formaldehyde, and we did both compression and bending tests with this material.

(Q for Gutierrez) What are the key selection criteria in adhesive selection for glulam bamboo?

Reply GUTIERREZ: Adhesive selection is a key factor in glue-laminated products. Adhesive selection has many drivers, including the application process, cost, primer requirements, surface preparation, temperature or pressure requirements during assembly and curing times, performance at elevated temperature, life, availability, and emissions during applications or after manufacturing. Different projects or different applications will have different drivers; therefore, users must define what their priorities are, and then choose the appropriate adhesive for their project or product.

3. PROPERTIES AND PERFORMANCE

Topic: Durability (concerns, treatment/mitigation strategies)

(Q for Ramage) How is bamboo treated for durability?

Reply RAMAGE: There are multiple possibilities. Thermal treatment, bleaching with hydrogen peroxide, soaking in borax, and inverted boucherie are among them.

See link: https://www.sciencedirect.com/science/article/pii/S1878029615003059

(Q for Ramage) Most development in engineered bamboo or timber has been targeted to temperate climatic conditions. What are the challenges for use in tropical region?

Reply RAMAGE: Engineered bamboo has been used in temperate and tropical regions. The challenges are similar – keep it dry, protect it from UV and insects, raise it off the ground for construction details.

(Q for Chui) How does engineered bamboo perform under rain, snow or sunlight conditions?

Reply CHUI: At the present time, my personal opinion is that engineered bamboo composites should not be used in wet conditions unless research has shown that it performs adequately in high moisture conditions after treatment. Given its similarity with wood, the bamboo material itself should perform adequately under snow and sunlight conditions. Potential degradation could occur in the adhesive though e.g. ultra-violet, low temperature effects.

(Q for Sands) Which chemical will you propose to improve durability of bamboo? In The Gambia, highly concentrated salt water from solar desalination is used.

Reply SANDS: Heat treatment and borates are our main focus. Saltwater works well as long as the connections are not made with metal since the salt can cause corrosion of the metal

(Q for Hinkle/Hammann) How do you address the microbial issues in humid environments? And (Hinkle/Hammann) Are there any modified treatment to bamboo unit or bamboo board to prevent fungal decay?

Reply HAMMANN: All products supplied by Lamboo are pressure treated with an environmentally friendly fungicide to help with decay of the bamboo from the inside out. Lamboo also stains, seals, and finishes all products supplied to any applications.

Reply HINKLE: Moisture management is a required focus for all lignocellulosic material. The shared hygroscopic properties of bamboo and wood must also be understood in the context of their application within a job. In most situations the appropriate treatment and installation procedures can manage this behavior.

(Q for Van der Lugt) What treatment do you use for high moisture conditions like the pool or bathroom examples you showed?

Reply VAN DER LUGT: For outdoor use (e.g. near pools), the best treatment to increase the durability for engineered bamboo is a combination of thermal modification (a modification technology well known in the wood industry, in which the molecular structure of the cell walls is changed upon heat treatment, increasing the stability and fungi / insect resistance without additions of chemicals) with densification,

see https://www.moso-bamboo.com/bamboo/how-bamboo-products-are-made/high-density-bamboo-production/?lang_selected=true

The result is a very durable, stable and rot resistant product known as Bamboo X-treme https://www.moso-bamboo.com/bamboo-outdoor/ which has a tested durability class 1 (EN 350, meaning at least 25 year life span even in ground contact), and comes with a guarantee of 25 years.

Bamboo materials for indoor applications can be used in high moisture conditions like bathrooms, but only if they are sealed professionally with a finish lacquer. This is similar to wood, but with the difference that in general engineered bamboo has a better stability which is favorable in high moisture conditions.

(Q for Dai) How do you lower the starch?

Reply DAI: Heat/steam treatment seems to be the common way to reduce/modify the starch. Some have tried using ultrasonic methods with some success. Work is ongoing in our group to further understand this as part of bamboo drying project.

Reply LUCAS: The age of the culm, when the culm is harvested, and how it is preserved affects the starch content.

(Q for Gutierrez) The only good quality construction bamboo I can get here in Haïti and the Dominican Republic is treated with diesel. How worried should I be?

Reply GUTIERREZ: It is hard to say how worried someone should be. Diesel is a highly combustible product. Therefore, bamboo impregnated with diesel will catch fire quicker than bamboo without any treatment. I have seen people using diesel to improve bamboo durability in countries like Colombia. I don't know how efficient diesel for this purpose is, but it definitely does not help to improve fire resistance.

(Panel) Does bamboo have inherent performance deficiencies compared to other construction materials (i.e., durability) and what are some of the steps that can be taken to mitigate these deficiencies?

Reply HARRIES: All materials have inherent limitations. All metals oxidize, should we not use metallics? We need to understand the limitations of a material and work within these. We have been doing this with bamboo construction for millennia.

Reply DAVIES: Typically, bamboo fibers are stiffer, and stronger in tension (or compression) than pine fibers. Their longer length (200-300mm vs 50-100mm for pine) makes them easier to glue with greater resiliency and ductility when stressed in a flexural application when approaching failure. Bamboo is less susceptible to mold and wood rot, and its fire performance is typically superior to timber pine. Those are all win/win attributes. The key is to know the values to associate with the material, and then to optimize

the design of the engineered product around those values. In that way, don't consider anything as a deficiency. It is simply a material property to design around.

Reply HAMMANN: Like any natural material, these products used in exterior applications will need to be maintained. Lamboo has done much research and development of stain and finish systems that work best for bamboo and has seen much success in continuing its practice of coating and finishing products for exterior applications. For interior applications, it is still required to at least seal and finish the materials to help avoid any intake of dirt or foreign materials into the material.

Topic: Properties (strength, stiffness, shear, etc.)

(Q for Ramage) You said that bamboo is much more elastic than wood. How can we take advantage of this for in construction? You said bamboo is strong but not stiff? What are the associated drawbacks with its low stiffness when used as a main structural material and how do we account for that in production and design? Is Bamboo scrimber stiffer than regular laminated bamboo?

Reply RAMAGE: Typically, a little bit stiffer, but not much. It is however much denser, so it is good for applications that require density (i.e., flooring) but not those that require stiffness, since the overall increase in density is far greater than the increase in stiffness.

(Q for Ramage) Considering the elasticity of the Bamboo, if we replace the iron with Bamboo for taller buildings, will these buildings become like a Leaning Tower of Pisa?

Reply RAMAGE: The leaning tower of Pisa leans because of its foundations, not its materials.

Reply HARRIES: If you replaced steel with bamboo on the basis modular ratio, you require in the order 20 times the amount of bamboo. You then must deal with creep, too.

(Q for Davies) Is the MOE or other engineered properties of EBP equivalent to LVL or better than timber products?

Reply DAVIES: For the same volume of material, the bamboo product will typically be stiffer and stronger than the timber. Often from 1.2 to 2 times better, depending upon the products being compared.

(Q for Ramage) What are the differences in performance between Bamboo and timber construction systems?

Reply RAMAGE: Currently they are not huge. The increased density of bamboo can be better for connections, but this depends very much on the engineering design.

(Q for Panel) Can any speaker explain bamboo usage in shuttering plywood (concrete formwork)? Also, what is the cost compared to normal shuttering plywood?

Reply DAI: Bamboo strip board with film facing is the most common type of shuttering formwork.

(Q for Davies) Can we use laminated bamboo planks for shuttering RCC slab casting and keep planks as timber/bamboo ceiling permanently?

Reply DAVIES: This idea is being explored currently on several projects. If the shuttering is just being used as a disposable formwork, which is then the final exposed ceiling. That is easy and definitely possible, but it may also be a wasteful use of the material. Typically, formwork shuttering gets and least 10 re-uses before it is replaced. If the laminated bamboo plank is made composite with the RCC slab, as part of the vibration and life/safety calculation of the floor system, that can be a highly optimized structural answer, but it brings forward a fire engineering challenge. ...timber has the same challenge today, so that is a challenge for any bio-based composite floor system. There are ways to allow this to occur, especially on smaller projects or when engaging in performance-based fire engineering, but it becomes a case by case evaluation.

Reply HARRIES. Such practice is likely ill advised. Concrete and bamboo are generally incompatible. Moisture causes volumetric changes in bamboo and bond cannot be assured. There are multiple other primarily durability-related concerns I could enumerate.

(Q for Davies) Compressive strength of bamboo is nearly half of its tensile strength. But bamboo is weak in shear? How can we improve the shear strength of bamboo?

Reply DAVIES: In an engineered system, I think this will come down to fiber orientation. If this is a beam application, creating a beam with flanges and a web, that fiber optimizes the material orientation for both conditions (flanges with the bamboo fibers parallel to the beam, and a web with the bamboo fibers at a 45-degree angle in both directions) will be an overall beam with less material for its capacity.

(Q for Davies) How can we improve shear strength in composite slab?

Reply DAVIES: In plane or out of plane shear? Out of plane (i.e., punching shear) often will not control as once material thicknesses are included for fire and vibration performance, punching shear is a smaller concern accept at unique locations. For in-plane diaphragm shear for wind and seismic loading, typically we see the challenge is not in the base material, but at the splice joints of the panels. How individual panels are connected on site to then develop their full member capacity is the critical condition to improve. We use labor and time intensive screws today. If there was a field created lap joint that could develop full base panel capacity, while addressing the practicalities of on-site construction and tolerance control needs, that would be a big advancement/advantage (a personal option).

(Q for Davies) How do you address the shearing capability between your bamboo beam and concrete block?

Reply DAVIES: For a bamboo beam to concrete block, I assume this would be at a beam to wall connection for vertical support. That typically (today) is achieved through either bearing connections of the beam landing on top of the wall or within a wall pocket, or through steel connector plates and either

lag bolts or through bolts. Both can be labor and time intensive, the choice is often driven by construction sequencing and architectural aesthetics.

(Q for Davies) When we use bamboo deck with concrete slab, will it form a seamless composite or will there be a gap in between the two layers and impact the mechanical strength of the structure?

Reply DAVIES: We have done both. The materially optimal answer is to mechanically connect the two, either with inclined screws applied in the field, or through several different proprietary connectors within the market. We worked recently with Mitek to develop and test an easier to construct connector than the incline screws, but I don't believe they have it commercially within the market yet (i.e. stay tuned and watch for more connection options to be coming out in the future).

(Q for Dai) Can you please expand more on why bamboo scrimbers are not suitable for structural applications?

Reply DAI: As mentioned earlier, it uses too much resin and its process particularly pressing is not efficient. As such, the product is too expensive compared to equivalent wood products such as parallel strand lumber. The product is hard to nail and MOE is not as high as it should be given its density.

(Q for Javadian) How does the dimensional stability of the LBV compare with bamboo strips?

Reply JAVADIAN: Using more treatment such as NaOH treatment allows BVL to be more resilient to weathering and other durability issues, also the resin used plays an important role in mitigating any challenges with dimensional stability.

Topic: Building design/architectural considerations

(Q for Ramage) What are the structure height limitations when using bamboo timber?

Reply RAMAGE: This depends on the engineering design appropriate for the material properties.

Reply HARRIES: Such limitations are rarely associated with a material but rather a use. Fire issues often dictate height issues. ISO 22156 is limited in scope to two storeys and 7 m. These limits were based almost entirely on the lack of data available for going beyond this.

(Q for Davies) Just thought it is worth pointing out, that DLT & NLT are one-way systems. CLT can be used as a two-way system. Comments?

Reply DAVIES: Fiber optimizes the design for the application under consideration. If you are dealing with one-way slab spans and a concrete topping resolves the in-plane diaphragm shear forces, then the DLT/NLT approach is fiber optimized and requires less material to do the same job. If you have no concrete topping slab and the floor system needs to resolve in-plane shear forces that can occur from multiple directions, a two-way system like CLT or mass plywood will be a more fiber optimized answer to the loading condition.

(Q for Davies) As a one-way system, DLT & NLT can be thinner than CLT, but CLT is ideal for 2-way systems, whereas DLT & NLT cannot be used). Comments?

Reply DAVIES: 100% agreed, see question response above...a challenge with CLT and 2-way systems to point out, the fiber depth to get to the strand-oriented fibers in a perpendicular direction within CLT greatly reduces the efficiency of the system (depth is a cubic function in a moment of inertial calculation). Most CLT is used today in one-way spanning systems because of this, with limited one-off 2-way applications that may occur. Each system has its benefits and drawbacks, use the right tool for the geometry and loading application being designed for. Rarely is it a one-size-fits-all optimized answer.

(Q for Davies) You have talked about construction systems of bamboo walls, columns, beams, slabs and bridges.... are there new systems investigated on house roofs and bamboo tiles?

Reply DAVIES: We have not seen this, but our projects are typically larger than houses, so it has not been a focus. I suspect this could be an interesting application.

(Q for Chui/van der Lugt) How much interest do EU or NA architects and engineers have for considering bamboo over wood?

Reply CHUI: My observation is that there is limited interest at the present time in North America. I believe largely because we have not seen many code approvals for engineered bamboo products. After the Conference, I did receive an email from a design engineer about the potential timeline to see bamboo product approvals in Canada.

Reply VAN DER LUGT: It is not a question about bamboo or wood, it is bamboo and wood (actually many architects don't see the difference between engineered bamboo and wood…and perceive bamboo as a kind of additional hardwood species), they go hand in hand in offering a biobased solution meeting climate and circularity (resource scarcity) problems in the built environment, which inspires many of the EU and NA architects. There is for sure an increasing interest in the use of mass timber (CLT, glulam, LVL) for the bearing structure of new buildings which engineered bamboo cannot offer (yet) due to price issues and lack of legislation / building codes. This is not problem at all as engineered bamboo offers a perfect finishing material indoors (wear resistant flooring, staircase, wall and ceiling finishing) and outdoors (cladding, decking, outdoor furniture) to be used on top of a mass timber bearing structure, Hotel Jakarta in Amsterdam offering a pristine example: https://www.moso-bamboo.com/bamboo-inspiration/hotel-jakarta/?lang_selected=true For more information about my views on mass timber and engineered working together in a sustainable building revolution please refer to my recent extensive interview with *Archdaily*:

https://www.archdaily.com/972254/the-potential-of-bamboo-and-mass-timber-for-the-construction-industry-an-interview-with-pablo-van-der-lugt

(Q for Thomas) Are you familiar with the use of cruck frames in England? These are centuries old and could easily be adapted to bamboo.

Reply THOMAS: I am familiar with Cruck framed housing. Curved culms were used in the Green School gym in Bali, but the technique to form them involved cutting a narrow sector from the culm, then folding it into a "polygonal" curve and due to the loss in strength reinforcing it to replace the lost bending stiffness. Better to do as Jorg Stamm does and use naturally curved sections, it is even possible to train the culms to desired curvature.

(Q for Thomas) What are the benefits and limitations of 3D printing in bamboo design and construction?

Reply THOMAS: In all forms of construction connections are numerous but consider the idea of a space frame. We have found that whilst investigating the development of a specific connection 3-D printing (as it currently exists) is extremely valuable in allowing various iterations to be tested. Once a connection is resolved then a more mass-produced method may become more economical. But 3-D printing methods are becoming more sophisticated and economical all the time. So- watch this space.

(Q for Rodriguez) How robust (*against storms/high wind/earthquake*) and secure *(against break in)* are the low-cost house design and build?

Reply RODRIGUEZ: A Kuna bamboo house is designed to resist wind speeds up to 160 km/hr and peak ground acceleration of 0.32g (2.94 m/s2). Walls are framed with bamboo poles at 400mm on center with bamboo strips running perpendicular to poles at 150mm on center cladded with metal mesh and render with watertight concrete. The house has steel doors and glass windows.

(Q for Panel) Will the recent growth in mass timber, tall building and hybrid construction impact EBP'sEBP's and their use in construction?

Reply DAVIES: For any building system application being opened up and advanced by the mass timber push happening within the AEC industry today, there is likely an opportunity for EBP's to also be used.

Reply HAMMANN: Even though laminated engineered bamboo is equal or better than other natural materials utilized in structural applications, cost (at this time) is really the driving factor that keeps EBP products out of this market.

(Q for Panel) What is the potential for bamboo in natural disaster reconstruction in developing countries?

Reply LUCAS: Enormous!

Reply HAMMANN: Bamboo used in core products which don't really present bamboo in an architectural sense would be perfect for these types of solutions needed for natural disaster and relief housing.

Topic: Connection systems

(Q for Ramage) Can we have bamboo connections using bolts similar to steel structure? How can bamboo building materials be connected if it is to replace steel?

Reply RAMAGE: We can use steel bolts and screws like connections in timber. The connections do not always perform in the same way, so a good understanding of the material and its performance is critical.

Reply HARRIES: I would advise to not think of bamboo as a replacement for steel. Perhaps cold-formed steel; but we don't use a lot of bolted connections in this type of construction. Screw-based connections are most common. There appears to be some data suggesting screw connections are not incompatible with bamboo.

(Q for Panel) If connections are key to further development, which do you think have more promise, mechanical or adhesive connections?

Reply Ramage: Nature uses adhesives, so that may be a lesson. Adhesives tend to work better when applies in controlled conditions, so factory pre-processing of engineered bamboo products can be an advantage.

Reply HARRIES: Mechanical.

Reply Chui: Adhesive connections are not easy to apply in the field and would only produce reliable results if they are fabricated in factory conditions. Mechanical connections are definitely the preferred approach.

Reply Davies: I encourage this to not be an either-or discussion, both will have their place. Adhesive connections placed in the field are minimal in their use today, so there would seem to be more opportunities for growth there, but typically neither should go away….or be considered in isolation.

Topic: Fire considerations

(Q for Gutierrez) Slenderness ratio of bamboo culms or bundled columns is one important parameter that will affect compression behaviour. How can we incorporate test results into actual structures under fire?

Reply Gutierrez: The tests performed during my research explain the reduction of compressive strength and modulus of elasticity of bamboo at elevated temperatures. With a heat transfer model, you can predict the reduction of the cross-section. A slender column under compression is likely to suffer buckling before failing due to crushing. If the column is also exposed to fire on one side, it will have an eccentric load, and then it needs to be designed to withstand a combined action of compression and bending while suffering degradation in its mechanical properties. This is a complex problem that would require analysis of a member with combined actions and degradation of mechanical properties over time.

Reply HARRIES: Technically (and likely legally) you cannot. One needs to conduct UL (Underwriters Laboratories) type testing and certify fire performance. Or, one can adequately protect bamboo from the effects of fire.

(Q for Gutierrez) Formation of black carbon film is the reason for making bamboo more fire resistant than wood, which prevents further penetration of fire. How can we quantify this?

Reply GUTIERREZ: Both wood and bamboo are charring materials, and char progression is usually quantified with charring rates. Charring rates are a simplistic approach to quantify thermal decomposition, and it depends on many factors, including fire exposure, density, thermal conductivity, moisture content, etc.

(Q for Gutierrez) Please comment on the chemical changes responsible for degradation of properties of bamboo composites when subjected to elevated temperatures?

Reply GUTIERREZ: Chemistry is not my area of expertise. However, I recommend reading Angela Solarte's thesis (chapter 3), where she explains bamboo's thermal decomposition through TGA and DTG analysis. Here is the link: https://espace.library.uq.edu.au/view/UQ:715c0a0

(Q for Gutierrez) First 10 to 15 minutes duration of a fire is important for the safety?

Reply GUTIERREZ: They are fundamental for life safety. During the fire growth, people can detect, react and evacuate a building on fire and respond to a fire incident. Usually, automatic suppression systems like sprinklers should act at that point to control the fire growth and avoid issues such as fire spread, smoke spread and flashover.

(Q for Gutierrez) Are there any commercial fire protective material or paint available for engineered bamboo products.

Reply GUTIERREZ: Some coatings are currently offered for timber that can work as fire retardants, and it would be great if they could be used or tested in laminated bamboo products. However, I am unaware of anyone offering them to be used on bamboo surfaces.

Topic: Hybrid components with bamboo

(Q van der Lugt) Any investigation underway on carbon fiber / EBP hybrids composite beams?

Reply VAN DER LUGT: MOSO <company> has primarily focussed for now on the development of constructional beams based on finger jointed (strip level) laminated bamboo beams. For this application MOSO <company> also received a German Technical Approval (very difficult to acquire) showing that it can be a very good and slender alternative e.g. for aluminium in curtain walls due to the high bending strength. For more information see https://www.moso-bamboo.com/product/bamboo-n-finity-construction-beam/

(Q for Davies) How feasible is bamboo biochar aggregate in concrete?

Reply DAVIES: I have not explored this yet in detail. I have seen the biochar discussion be around concrete SCM's, though, not as an aggregate. This is an application I am not familiar with.

(Q for Davies) What is the issue with the interface between concrete and bamboo?

Reply DAVIES: They are dis-similar materials that don't inherently work together unless mechanically anchored to do so across that interface. There are multiple constructability and final assembly challenges (and mutually supportive) benefits of using both materials in a composite application. Concrete is economical in compression and shear, and it doesn't burn. Bamboo is economical in tension, and as a surface covering for formwork shuttering, and in final finish. Finding ways to celebrate what each material does best, and then getting them to work together is a win/win….when the mechanical connector is economical.

Reply HARRIES: Bond! Or lack thereof. See https://doi.org/10.1617/s11527-018-1228-6

(Q for Javadian) The graph on the concrete beam tests shows bamboo reinforced beams compared to ACI calculated expected values. Did you also test a rebar reinforced sample as a control?

Reply JAVADIAN: Yes, we did, as a comparison, but we only used the common type of rebars used in Indonesia as comparison purpose. There are definitely higher grades rebar available, but they come at a cost and majority of homes in developing areas in Indonesia or other developing countries are not built using high grade steel or concrete. Also, we compared our results to FRP reinforced concrete as we think that is more relevant in terms of material properties and characteristics. Just to highlight we do not use bamboo as reinforcement, but we used bamboo veneer lumber (BVL) as reinforcement in concrete beams.

(Q for Javadian) I think normal steel bars as shear reinforcement along with bamboo as tension in beam will work nicely and more practically. What is your opinion?

Reply JAVADIAN: I believe using natural bamboo cannot be a long-term solution due to its durability and dimensional stability issues. However, using BVL technology in connection with steel could work in special cases, we have not tested this combination so far.

(Q for Javadian) The strength per volume in bamboo is lower than steel. Are you dimensioning the rebars in the ratio of this difference?

Reply JAVADIAN: We work with strength to weight ratio, therefore if you compare the bending strength normalized by the density you will see that the two come so close and sometimes depending on the type of bamboo used to produce the bamboo composite it can also be better than steel.

Reply HARRIES: It is critical to remember that concrete rebar is less about strength than stiffness. While the ratio of steel to bamboo strength may be about 5, the modular ratio is easily 20! See *https://doi.org/10.1617/s11527-018-1228-6*

(Q for Javadian) As a reinforcement for structural concrete, dimensional stability (shrink and swell) is important. How is the dimensional stability of the LBV you used, compared with bamboo strips?

Reply JAVADIAN: As explained earlier, we have carried out weathering tests for the BVL and the results show that in the long term we might need to add on a layer of protective coating to enhance the resistance against shrink and swell. However, when is compared to strips, BVL performs better given the bamboo fiber treatment we use and the type of resin employed.

Topic: Codes/Standards

(Q for Chui) Is there a way to start producing/selling bamboo products in Canada before the standards get published?

Reply CHUI: It is possible if an engineer takes responsibility for the design and local building officials approve. This will require the engineer to submit background papers and reports to support the design. This was how CLT got started.

(Q for Chui) Although few standards currently exist, how feasible is an ISO standard on Engineered Bamboo? What is the current feedback on those standards? Because of the large numbers of species and their variability by country, should we be focusing more on standards at the local level? ***(FYI: The ISO standards in bamboo and rattan were already adopted as Philippine National Standards.)***

Reply CHUI: There has been interest in developing ISO standards on engineered bamboo composites among the countries that are producing them. Most standards such as test methods, product evaluation and structural design should not deviate much between countries. I believe it is much more efficient to mobilize international expertise to develop international standards that could be adopted by individual countries with minor modifications that suit local conditions. This should ensure consistency in evaluating and using the products and avoid future trade and technical barriers.

Reply HARRIES: ISO Standards for engineered bamboo are presently being developed. ISO are model codes and their adoption will typically include a national annex intended to provide relevant local data and provision.

(Q for Chui) Is the class system also compatible/transferable for clumping tropical bamboo, compared with subtropical where bamboo is monopodial?

Reply CHUI: Yes, this is the key benefit of the structural class system. It is based on product performance, rather than species, manufacturing process and format of the products.

(Q for Chui) What would be the motivation for NA code officials to consider engineered bamboo in construction?

Reply CHUI: As building codes (in Canada at least) are moving towards net-zero carbon design, a wider choice of low carbon foot-print building materials should be of interest to code committees.

Reply HARRIES: Industry needs to advocate for its use and advocate development of new standards or standards of equivalence. It is not the role of building officials to determine how to safely utilize a new product. The manufacturer or advocate must provide the building official with the confidence to approve this. This is typically done through codes and standards.

(Q for Van der Lugt) How has Lamboo managed to use structural applications of bamboo? My understanding is that bamboo for structures is still not certified.

Reply VAN DER LUGT: See also answer above; MOSO <company> has primarily focussed for now on the development of constructional beams based on finger jointed (strip level) laminated bamboo beams. For this application MOSO <company> also received a German Technical Approval (very difficult to acquire) showing that it can be a very good and slender alternative e.g. for aluminium in curtain walls due to the high bending strength. For more information see https://www.moso-bamboo.com/product/bamboo-n-finity-construction-beam/

On the short term we don't see a market for structural beams, walls or floors to substitute CLT or glulam. In our opinion this also does not make sense; not even considering the lack of building codes and technical approvals to safely apply engineered bamboo in these applications, it makes far more sense (from both environmental, logistical and cost perspective) to make CLT and glulam from locally sourced softwood in EU and NA. For bamboo growing and processing countries (e.g. China and India) this may be different.

Reply HAMMANN: Since Lamboo has been focused on testing materials through 3rd party certified laboratories against ASTM Engineered Wood Standards, Lamboo has developed the technical information required by structural engineers to verify sizing of post and beams needed per the project. Currently, all projects that Lamboo supplies structural beams are engineered "project-specific" which is a common practice in the N.A. industry. Most structural projects that we supply to are specialized as it is hard to compete against current materials used in glu-lam and CLT applications due to local wood materials being in the market for as long as it has and saturated in pricing. Due to increases in wood price though, laminated engineered bamboo (Lamboo) may become a more viable option in the near future. Combining Lamboo with other natural or engineered products is also a viable option to help reduce overall costs of engineered products. This is another area of options that Lamboo has been focused on for the last couple years.

(Q for Zea Escamilla) Has the results of your E-Bamboo Cement Composite study using ECOINVENT been presented to impact investors, and can these be harmonized with the SBTs and the ISO Net Zero Standards? In line with COP 26, the Philippine Sustainable Financer Roadmap was published in April 2021. The 2020 MSME Guidebook was published in 2020.

Reply ZEA ESCAMILLA: No, it has not been presented outside academic circles. It would be possible to harmonize it as they use the same evaluation method, but this work needs to happen outside the academia.

(Q for Rodriguez) Can the new set of requirements for LCA, PCR, EPD, name it for businesses, ratings and codes hamper the fast development/uptake of bamboo, esp. with regard to investments and financing of the sector?

Reply RODRIGUEZ: I am not aware of what are the new requirement for LCA & EPDs, but if bamboo manufacturers cannot provide EDPs to clients that require it, then their product will not make it to projects. A LCA is usually done and paid by client when required.

(Q for Jacobs) Are there initiatives underway to harmonize all the ratings/codes, etc?

Reply JACOBS: There is always discussion in harmonizing the different rating systems, but at the moment….no. We did a bit better with the codes a few years ago when there was an agreement made so that the technical contents of the International Green Construction Code (IgCC) would come from ASHRAE. 189.1, so those two codes were essentially merged.

4. ENVIRONMENTAL/SUSTAINABILITY ISSUES

Topic: Growing and production

(Q for Sands) How about keeping the value chain for bamboo products as far as possible within the countries where bamboo can be farmed?

Reply SANDS: This reduces transport and helps local development. Our goal is to develop local markets for each location in which we are working as this does reduce transport and help with local development.

(Q for Hinkle) Can you elaborate on how the key features of the BamCore Wall System enables it to achieve Net Zero Emissions?

Reply HINKLE: There is an oversimplification of how building components can lower the carbon footprint of a building. Whole Building LCAs must ultimately be used at the point of design with the objective to lower the entire building's embodied carbon to a minimum. This in many ways is today more important than the long-term energy efficiency of a building. In this regard, by substituting the bamboo-based product there are two carbon savings/reductions: (1) the directly stored carbon in the product used and (2) how the use of that (carbon storing) product allows for a reduction of other higher embodied carbon components. The simple example is bamboo engineered products can provide a floor or subfloor-composite system in a high rise with less total weight than the conventional steel deck and

concrete topper. In this application the bamboo-based product gets its own credit for the biogenic carbon stored but also for the reduction of the use of higher embodied energy products.

(Q for Davies) What are the main environmental impacts of glulam bamboo based on life cycle assessment?

Reply DAVIES**:** Shipping and handling, adhesive use & curing (negative impact), carbon sequestered (positive impact)

(Q for Hinkle/Hammann) How environmentally friendly is the process of converting bamboo into engineered bamboo? Are we generating more carbon emissions in that process versus using round bamboo?

Reply HAMMANN: Since engineered bamboo does require the use of machines and energy to convert the round bamboo poles into materials used to make-up the final product, we do create carbon emissions. But this can be said with any process that is used to convert a raw product into an engineered product. Since there is more processing that has to happen in producing engineered bamboo products, yes there is more carbon emissions produced than just using round poles. I do not know how much more as Lamboo is strictly focused on architectural-grade and engineered products.

Reply HINKLE: Questioner is right; we have no need to convert round bamboo into engineered bamboo as long as we don't want to occupy structures greater than two stories or use bridges, etc, requiring high load capacity. Use of round bamboo, unfortunately, is limited by our ability to make connections capable of the load demand currently being pressed for in and around the world today.

Topic: Building materials (embodied carbon, sequestered carbon)

(Q for Ramage) The thing is that 1 kg engineered bamboo store 1.8 kg CO2. Is this included in the calculation of emission during processing?

Reply RAMAGE: Generally, it is not included – this storage potential is not currently allowed for in most LCAs, so it is an added benefit that we can calculated and verify (as Pablo has done) but it is reported independently.

Reply VAN DER LUGT: See also this blog https://blog.moso-bamboo.com/how-much-co2-is-stored-in-bamboo?lang_selected=true I wrote on this topic based on the MOSO <company> engineered bamboo products (so also including moisture and glue content), based on the MOSO EPDs where the biogenic carbon storage is also verified: https://www.moso-bamboo.com/lca/

(Q for Ramage) Is there an algorithm or calculation to measure if carbon footprint of EBP is positive or neutral in comparison to timber?

Reply RAMAGE: It is dependent on the growing, harvesting and processing – so EPDs for each material are important.

(Q for Ramage) About the embodied energy, in the case of laminated bamboo or wsb, is it possible to compensate the emissions for the transformation processes by considering all the benefits that the plant produces? Can bamboo get climate credit like electric cars?

Reply RAMAGE: Engineered bamboo products do not yet get credit. We and others are working on it for the storage potential.

(Q for Davies) You'veYou've presented a perspective on sustainability that includes optimizing material use and considering hybrid solutions - consistent with circular economy principals. How is that message being received by mainstream stakeholders?

Reply DAVIES: Very well. The challenge is material supply, and the ability to have a competitive bidding process with more than one supplier for any one product or material. Within the mass volume, bigger projects, EBP's will find the fastest market acceptance and use when it is packaged as a competitive alternative to current systems, not as a one-off totally different system.

(Q for Mei) Will there be an English translation of the book?

Reply MEI: Currently we don't have the English version of the book. However, we have published the data from the book. Please refer to the following two papers:

Gu, L., Zhou, Y., Mei, T., Zhou, G., Xu, L., 2019. Carbon Footprint Analysis of Bamboo Scrimber Flooring—Implications for Carbon Sequestration of Bamboo Forests and Its Products. Forests 10, 51. https://doi.org/10.3390/f10010051

Yufeng Zhou, Chong Li,Zhengwen Niu, Longdong Xiao, Lei Gu, Rong Yu, Zhipeng Ge, Lv Zhou , Lin Xu, Guomo Zhou*. Assessing carbon footprint and carbon emission reduction potential of bamboo flooring board by three manufacturing processes in China. Under review.

(Q for Mei) Can the data be used as part of the process to integrate bamboo into international carbon markets?

Reply MEI: Carbon transfer into bamboo products has been integrated into two bamboo carbon sequestration methodologies, which were compiled by the National Development and Reform Commission of China. We are putting effort to make these methodologies available to the international market, such as developing methodologies in Verra. We hope the work will success in the near future. More related reference about the bamboo carbon sequestration project could refer to the following reports from INBAR.

Pablo van der Lugt, Trinh ThangLong, Charlotte King, 2018. Carbon sequestration and carbon emissions reduction through bamboo forests and products. INBAR, Beijing.

King, C., Pablo van der Lugt, Trinh Thang Long, Li Yanxia, 2021. Integration of Bamboo Forestry into Carbon Markets. INBAR, Beijing.

Reply LUCAS: It is extremely complicated, and yes, people are working towards this. But no smallholder farmer will be able to develop a carbon eligible project without being part of a much larger project - this is never going to be realistic regardless of growing carbon markets (let's also remember that forest carbon markets grew like this in 2007-2010 and then for forestry dropped off completely.) This is not a realistic market to bank on for individual farmers. There are some small projects currently going through the Verra process, with individual communities engaged in a benefit sharing arrangement. Projects must be designed from the outset to meet eligibility requirements. The standards are specifically structured to ensure that it is extremely hard to suddenly get accredited for an existing project - this is the core of additionality, one of the key eligibility components for carbon forestry. In addition, a project must prove longevity - a guarantee with nominal risk - that the bamboo will be maintained to a certain standing stock, over a minimum 30–50-year period. This is not realistic or feasibility for a smallholder without being part of a larger project.

There are extremely strict frameworks, requirements, and consistency across the reforestation activities required. Such frameworks and the eligibility requirements are available on the website of Verra; however a project developer has to be able to navigate the Verra requirements, the methodology requirements (typically CDM), the host government requirements, and have the technical ability to develop a carbon accounting for the project activities.

(Q for Mei) What is the percentage CO2 reduction of bamboo sequestration as compared to trees (forests and plantations)?

Reply MEI: Bamboo carbon sequestration is relatively high. For example, for Moso bamboo growing in Anji, Zhejiang Province, its carbon sequestration is 24 t CO2 ha-1 year-1 (2011-2014). While for Chinese fir growing in Huitong, Hunan Province, its carbon sequestration is only 11 c. Other observed carbon sequestrations of forest ecosystems range from 6 – 21 t CO2 ha-1 year-1 (2003-2006).

Reply VAN DER LUGT: See this INBAR report for more information on this topic: *https://www.inbar.int/resources/inbar_publications/carbon-sequestration-and-carbon-emissions-reduction-through-bamboo-forests-and-products/*

(Q for Mei) Is it species-limited as far as laminated technology is concerned?

Reply MEI: Due to the specification requirement of laminated board, selected bamboo culms should meet a culm-wall thickness > 7 mm. Therefore, bamboo species with a culm-wall thickness less than 7 mm cannot be used to produce laminated boards.

(Q for Mei) Do the bamboo products (such as flooring) align with the ISO standards?

Reply MEI: The question is out of my research field. However, I think Pablo may be able to answer this question.

REPLY VAN DER LUGT: There is a European norm for Bamboo Flooring, no ISO standard is applicable yet. EN EN17009 is a relatively new standard. At least MOSO® confirms to align with this standard, not clear if all suppliers do that.

(Q for Mei) Are the last four products in the table so energy extensive that their carbon footprints are so high? Are they simpler products?

Reply MEI: Compared to the unfolding and flattening bamboo floor with green bark (-18 kg m-3), the last four bamboo products (Sliced bamboo veneer, Bamboo curtain, Bamboo mat, and Bamboo carpet) have relatively high carbon footprints, i.e., 152, 118, 152, 112 kg m-3, respectively. The high carbon footprint is mainly attributed to the high energy costs during the production processes. Such processes account for 79%, 77%, 63%, and 74%, respectively, of the entire carbon footprints of the four bamboo products.

(Q for Mei) How do you measure Eddy covariance for carbon balance? How is underground biomass measured?

Reply MEI: 1) The eddy covariance method was used to calculate the carbon sink capacity of terrestrial ecosystems, that is, by measuring the covariance of the vertical wind speed and the fluctuations of CO2 and water vapor concentrations in the atmosphere to calculate the CO2 and water vapor exchanges between the atmosphere and biosphere. It is the standard method of FLUXNET, an international carbon flux observation network. NEE (net ecosystem exchange of CO2) is directly measured by the flux eddy covariance tower and is usually integrated every 30 minutes. When NEE is negative, which means the net absorption of CO2 of ecosystems from the atmosphere; and when NEE is positive, which means the net release of CO2 to the atmosphere.

2) underground biomass could be obtained in two ways. The first way is the harvesting method, which is the most destructive but accurate way. With this method, one can build the relationship between aboveground and below ground biomass for a specific bamboo species. The second method is with existed below ground biomass model, which is more accessible and non-destructive. With such a model, one can predict the belowground biomass by knowing the culm diameters or heights of sample bamboos in a bamboo forest. However, I suggest calibrating the model before applying it to your studied bamboo forest by harvesting a few bamboos if it is possible.

(Q for Mei) Besides harvesting the bamboo clump, are there any example where carbon stock from bamboo plantation has been sold?

Reply MEI: Except for harvesting measurement, carbon stocks of bamboo forests can be evaluated through biomass equations with some sample data from the project stands, e.g., diameter at breast height or tree height.

(Q for Mei) How can we develop methodologies for carbon sequestration at a local level?

Reply MEI: Many existing methodologies for carbon sequestration worldwide, e.g., CDM, VCS. One could develop a new methodology that the current existing methodologies cannot satisfy the project. There is

a guideline for developing a methodology. As in VCS, to approve a methodology, one should go through the approval processes for the concept note and methodology. There are several steps to approve the concept note and methodology, e.g., development, evaluation, and acceptance of the concept note; development, review, public stakeholder consultation, VVB assessment, and final review of the methodology.

(Q for Zea Escamilla) Which species of bamboo can give more benefit, both from an industrial and/or carbon capture and storage perspective?

Reply ZEA ESCAMILLA: In general woody bamboo species would provide best opportunity due to its land productivity rate. Nevertheless, this needs more research especially.

(Q for Rodriguez) How can we audit the carbon sequestration for carbon credits etc.?

Reply RODRIGUEZ: There exist internationally recognized organizations that audit carbon projects and its associated credits. Verra and Gold Standard are amongst the largest.

(Q for Panel) A 2016 paper questions bamboo's carbon storage capabilities. See Zachariah, E. J., Sabulal, B., Nair, D. N., Johnson, A. J., & Kumar, C. S. (2016). Carbon dioxide emission from Bamboo Culms. Plant Biology, 18(3), 400–405. https://doi.org/10.1111/plb.12435 Does the panel think that there is a potential source of concern here?

Reply HARRIES: If this is the paper I am thinking of, read the paper. The science is poor. There appears to be no replicate specimens and if there were there is no measure of variation and significance. I have reviewed this paper and have further concerns. This paper is a single, rather poorly obtained, data point.

Reply LUCAS: I absolutely agree with Kent Harries. Totally refutable.

Topic: Marketing Opportunities for bamboo in the West (EU, N. Am. etc), comparative pricing

(Q for Panel) How do we promote bamboo products and construction systems in states like Florida, Texas, Louisiana?

Reply LUCAS: Capital investment, long-term commitment, and collaboration.

(Q for Dai) What is the potential for bamboo products in international markets

Reply DAI: As plastics replacement, bamboo products for household items and packaging will continue to grow. For building applications, more innovations are needed to reduce manufacturing cost, improve supply chain and establish building code and standard for engineered bamboo products. In the meantime, more structural bamboo and/or hybrid bamboo-wood products can be used in demonstration projects as the drive for carbon neutral building construction intensifies.

(Q for Sands) Bamboo, while not native to Hawaii, has been there for several hundred years and is now part of the culture. What is the best strategy for introducing engineered bamboo to the US Mainland where a wood culture is mainstream?

Reply SANDS: We are developing products that solve current problems in the US wood industry such as log utilization. We are in the early stages of a project for the Hawaii islands.

Reply LUCAS: Prove it to be the right material for our current crisis: regenerative, perennial, ecological benefits (builds soil, retains moisture, provides wildlife habitat), provides jobs, etc.

(Q for Jacobs) How can I get EPD certification by individual consulting firm or association?

Reply JACOBS: EPDs are not certifications they are environmental impact transparency documents for individual products. A firm, association or company does not get an EPD on itself.

(Q for Jacobs) Which software do you use to do LCA? Which one would you recommend?

Reply JACOBS: WAP has capability and can use all the existing LCA software in the marketplace. Out of those many, two of the most frequently used are GABI and SimaPro.

(Q for Jacobs) What are the ramifications of EPD on global public procurement and "green investments"?

Reply JACOBS: EPD are starting to be used by procurement teams/people to understand the true impact of a product. Certain authorities having jurisdictions around the world are setting individual product global warming potential limits and that information can be found on the EPD.

(Q for Jacobs) How does ESG grading impact financial incentives?

Reply JACOBS: There are numerous organizations doing ESG 'grading', so it really depends on which one's investors in an organization are looking to for understanding. But I will say that several financial firms are creating their own internal metrics around ESG disclosure and making decisions based off of that.

(Q for Van der Lugt) How does engineered bamboo compare to EWP in EC countries with regard to price point, attributes and performance?

Reply VAN DER LUGT: Regarding price point; see also my answer above: This really depends on which product you are referring to as MOSO <company> has many different products for outdoor and indoor use, made via different manufacturing processes: https://www.moso-bamboo.com/bamboo/how-bamboo-products-are-made/

As a very rough rule of thumb you can say that the indoor flooring products are in the same price range as a good quality FSC certified oak floor and outdoor products are slightly less expensive than the best quality FSC certified tropical hardwood species. However, recently wood prices increased significantly in

Europe, therefore this situation might change and engineered bamboo becomes even more competitive in pricing.

Regarding performance, this really depends on the product and application. In general engineered bamboo has a similar or better structural performance compared to laminated softwood, see for example the structural N-finity beam which received a German Technical approval https://www.moso-bamboo.com/bamboo/certifications-dibt/. Performance may also refer to many other aspects such as durability, VOCs and fire safety for which the MOSO <company> products show very good performance covered by various certifications https://www.moso-bamboo.com/bamboo/certifications/

But in general the use of mass timber and engineered bamboo should go hand in hand, see also my answer above and my interview for Archdaily https://www.archdaily.com/972254/the-potential-of-bamboo-and-mass-timber-for-the-construction-industry-an-interview-with-pablo-van-der-lugthttps://www.archdaily.com/972254/the-potential-of-bamboo-and-mass-timber-for-the-construction-industry-an-interview-with-pablo-van-der-lugt

Topic: Key challenges and opportunities for promotion/advocacy

(Q for Ramage) How effective is ""playing the green card"" been in driving acceptance of bamboo as an alternative construction material?

Reply RAMAGE: Most specifiers take it up because it is the right material for a number of reasons, not just because it is a natural biocomposite.

Reply LUCAS: In the past 20 years, this market has grown tremendously, and I believe the “green card” has been beneficial. However, “greenwashing” can be disastrous, as evidenced by what happened to bamboo fabric retailers.

See link: https://www.justice.gov/opa/pr/kohl-s-and-walmart-agree-pay-55-million-combined-penalties-alleged-deceptive-violations#:~:text=May%205%2C%202022-,Kohl's%20and%20Walmart%20Agree%20to%20Pay%20%245.5%20Million%20in%20Combined,)%2C%20announced%20that%20Kohl's

(Q for Ramage) How do bamboo composites support a circular bio-economy?

Reply RAMAGE: Engineered bamboo is reusable in much the way wood and steel are – if we are designing for disassembly and reuse, we can keep the bamboo products in use through multiple generations of structures.

(Q for Ramage) Considering the potential benefits of Bamboo in both Construction and Carbon Capture and Storage, why has there been so little uptake?

Reply RAMAGE: Construction is a conservative industry, and change is slow where our conventional materials are so entrenched.

(Q for Sands) Is there any social stigma with using bamboo in the Philippines and other parts of the world? Also, in Indonesia, bamboo is considered a poor man's building material. How can we raise the prestige of bamboo to a higher level?

Reply SANDS: Though there is still much work to be done, the perception of bamboo in the Philippines and elsewhere is changing due to proper treatment which provides longevity to the bamboo products and due to the creation beautiful materials and designs that showcase bamboo. The efforts of numerous architects and designers working with bamboo have raised and will continue to raise the prestige of the material. We should also share the environmental benefits of this rapidly renewable material whenever the opportunity arises.

(Q for Hinkle) In the immediate term, what structural applications show the most promise and could that success help pull through other bamboo products and applications?

Reply HINKLE: Currently we are focusing on the largest but also hardest part of the building-construction value chain, i.e. the vertical load bearing. Because bamboo-based building products are generally more expensive to produce than local competing wood products, the bamboo-based product must embody additional value-additions like saving labor, improving thermal or acoustic performance, etc, to offset the “green premium”. The reason we have the opportunity that we have is precisely because the industry is extremely resistant to new solutions. If it weren’t so challenging it would have already been done by others before now. Probably we’ll get there from both directions: mass produced and custom-designed products.

(Q for Hinkle) Can you speak a little more about the World Bamboo Foundation's work in addressing rural poverty and the impact that it is having?

Reply LUCAS: The World Bamboo Foundation was formed at the end of 2020 under the wing of the World Bamboo Organization. The first year WBF supported 8 research Fellowships related to how the commercialization of timber bamboo can help alleviate rural poverty and address climate change. You can read more about this on the website. We hope to have research results published soon; we’re proud of the research topics selected by the Fellows and look forward to much more.

(Q for Hammann) Does the bamboo industry have an equivalent to the Canadian or American Wood Councils?

Reply HAMMANN: The main standard that we test our materials to is ASTM. Since this is one of the most recognized testing standards in the world, we find it best to test against the guidelines set forth in these standards. Based on the strength, performance, density, and other positive characteristics of engineered bamboo, I find in most cases that our products do meet standards as presented by Canadian and American Wood Council.

(Q for Hammann) Is there a role for demonstration projects?

Reply HAMMANN: Lamboo's website and photo gallery is load with actual projects where these materials have been specified by architects, designers, and engineers and install by local contractors. We have really pioneered the use and utilization of this amazing product throughout a variety of building applications.

(Q for Hammann) What has been done around the education of design professionals and engineers in North America?

Reply HAMMANN: Lamboo has developed Continuing Education Course focused around specific products and general uses of engineered bamboo that we present in person or virtually to continue and grow awareness of our products. Lamboo has also developed marketing campaigns that has helped grow the industry and we truly are the leader of this technology in North America and other geographical locations.

(Q for Hammann) How successful have we been in changing public perception and acceptance by building code authorities?

Reply HAMMANN: The main "issue" that Lamboo and I believe other engineered bamboo providers are running into is awareness. Since this product is still in the "infancy" stages of the building market, most of the public just doesn't know that laminated engineered bamboo can be used in the applications that Lamboo has been successful in providing. Lamboo was responsible to integrating LVB (laminated veneered bamboo) into the ASTM Engineered Wood Division. Much more work still needs to be done.

(Q for Hammann) Is there a role for government in any of these scenarios?

Reply HAMMANN: In my opinion, the focus on using sustainable building material is at an all-time high. If we can have our government see beyond other "renewable" or "sustainable" energy sources, laminated engineered bamboo is hands-down the next best option in building materials.

(Q for Zea Escamilla) How can you convince the world that can use bamboo production and application to benefit society?

Reply ZEA ESCAMILLA: We need to carryout demonstration projects, especially those showing the effect of the bamboo value chains,

(Q for Zea Escamilla) I think Agroforestry is definitely an option. What do you think about Bamboo planted together with other species?

Reply ZEA ESCAMILLA: Diversification is always a good option; I cannot give the details as this is not my field of expertise.

Reply LUCAS: Gone are the days of monocultures without consideration of biodiversity. Small-holder farmers always have companion crops to grow alongside the bamboo.

(Q for Mohanty) Is there a monoculture concern in planting so much bamboo?

Reply LUCAS: I follow the role models of WWF's New Generation Plantation platform, which conform also to FSC requirements. Creating a bamboo plantation requires multi-stakeholder partnering to take care of local biodiversity, ecosystem services, indigenous communities, water rights, wildlife habitat, etc.

(Q for Chui) What are the main challenges facing engineered bamboo as a construction material? How can one grow market share?

Reply CHUI: My opinion is the lack of standards for evaluating engineered bamboo. For it to be considered as an alternative to engineered wood, design properties should be included in design standards and products recognized by building codes. This could be a long-term process. In the short-term, code approvals for proprietary engineered bamboo products would be a good first step.

(Q for Panel) What are some of the actions we can take to encourage greater acceptance of bamboo in construction?

Reply HAMMANN: Awareness – architects, engineers, designers, developers, building owners, and many more professionals need to know that these products exist and need to be utilized in building applications. We need to "decarbonize" projects and inspire the use of one of the world most rapidly renewable resource, bamboo.

Reply CHUI: A lot can be learned from the CLT pathway. A couple of suggestions: 1. demonstration projects promoted by well-known architects and engineers; 2. publication of technical design guides.

ADDENDUM.

Speaker Name & topic & Email address

Michael Ramage, Cambridge U. – Macro view (need and examples for low carbon buildings) mhr29@cam.ac.uk

Donald Davies, MKA – Opportunities for bamboo in building sector (potential products for large buildings and affordable housing) ddavies@mka.com

Y. H. Chui, University of Alberta - Standards & Regulatory routes for engineered wood and bamboo as a building material yhc@ualberta.ca

David Sands, Bamboo Living/rizome – Building construction: From round bamboo to engineered bamboo david@rizomeco.com

Hal Hinkle, Bamcore – Product technology (success and lessons learnt) hal@bamcore.com

Jeran Hammann, Lamboo – Product technology (success and lessons learnt) jeran@lamboo.us

ENGINEERED BAMBOO FOR SUSTAINABLE CONSTRUCTION CONFERENCE
Virtual / March 17-19, 2022
FOLLOWUP TO PARTICIPANTS QUESTIONS

Pablo van der Lugt, Technical University Delft | MOSO International – Modern architect design with bamboo pvanderlugt@moso.eu

Chunping Dai, UBC, Moderator - Current state of engineered bamboo research chunping.dai@ubc.ca

Kent Harries, U. of Pittsburgh – Characterizing properties of bamboo KHARRIES@pitt.edu

Neil Thomas, Atelier One, UK – Innovative bamboo products and structures

Dongsheng Huang, NFU, China – process and properties of engineered bamboo, presented by Tingting Mei dshuang@njfu.edu.cn

Alireza Javadian Engineered bamboo and bamboo reinforced concrete alireza.javadian@kit.edu

Mateo Gutierrez, CLTP Tasmania – Fire performance of engineered bamboo mateogutierrezg@gmail.com

Sol Rodriguez, UBC – Bamboo social housing slewites@mail.ubc.ca

Lucas Oshun/Tom Goodham, Regeneration Field Institute – Business models for engineered bamboo products loshunintl@gmail.com tom@thomasgoodham.com

B.N.Mohanty, IPIRTI, Value Chain Management and how it relates to sustainability of bamboo as a construction material bnmohanty86@gmail.com

Josh Jacobs– WAP Sustainability Consultants - Carbon measurement of building materials josh@wapsustainability.com

Edwin Zea Escamilla, ETH-Zurich - Environmental potential from the use of bamboo in construction zea@ibi.baug.ethz.ch

Guomo Zhou, ZAFU - Carbon sequestration of bamboo zhougm@zafu.edu.cn

Ian De la Roche, UBC – Moderator ian.delaroche@ubc.ca

Kewei Liu, International Bamboo and Rattan Organization kwliu@inbar.int

Cherla Sastry, Univ of Toronto – Moderator cherla.sastry@gmail.com

Susanne Lucas, WBO – Moderator info@worldbamboo.net

Yiping Lou, Zhejiang Agriculture and Forestry University – Moderator yplou@zafu.edu.cn

John Innes, UBC – Moderator john.innes@ubc.ca

Kate Semple, UBC – Support katherine.semple@ubc.ca