Engineered Bamboo Products
A sustainable choice?

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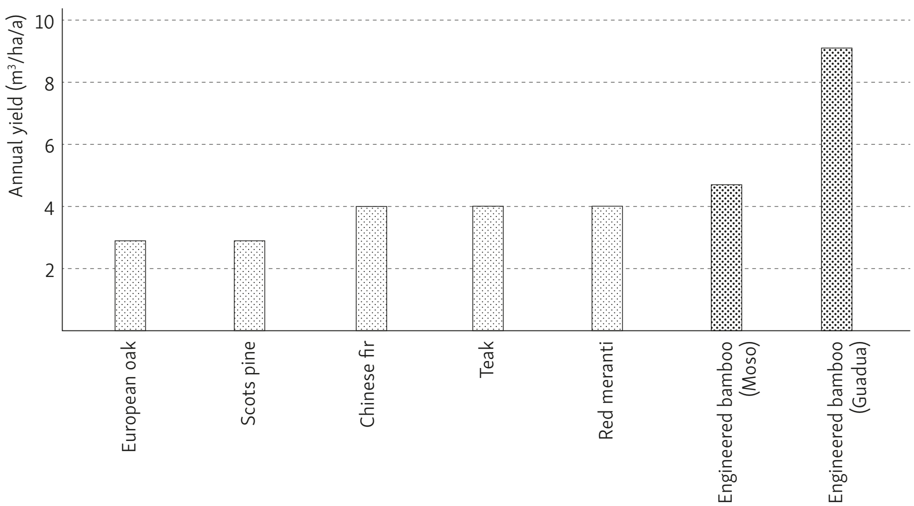
ENGINEERED BAMBOO PRODUCTS – A SUSTAINABLE CHOICE?

Pablo van der Lugt



▲ **Annual yield of semi-finished material for various wood and bamboo species in cubic metres produced per hectare per year.**

Given the increasing scarcity of resources, a transition from the traditional linear "make-take-waste" production scenario to a circular model is essential to be able to meet the needs of future generations. In the circular economy concept[1] products are designed in such a way that their components fit as nutrients in either the biological cycle – biodegradable after use, recycled, and regrown by nature itself – or the technical cycle of industrial non-renewable materials whose finite stocks need to be secured by high-level recycling.

Although the current focus of circular economy endeavours seems to be on incumbent high-tech industries of the techno-cycle, a shift towards the biological cycle or a bio-based economy seems more logical in the long term, due to its inherent renewable nature. With an increasing world population, and an increasing per capita consumption, human society will rely on high-yield cultivated building materials, such as bamboo, to meet future demand. Although sustainably grown wood will have an important role to play in this bio-based economy, in particular supplies of high-performance hardwood will be insufficient. Due to slow growth and long rotation cycles, hardwood forests will remain susceptible to deforestation.

As bamboo is a giant grass species, with many culms deriving from one mother plant and a fundamentally different way of growing and harvesting than trees (crop-like harvesting scheme based on annual thinning with high yields), it is less susceptible to clear-cutting, providing farmers with a steady annual income without a need of replanting. Furthermore, as Peter Edwards and Yvonne Edwards-Widmer describe in their contribution (see p. 80), bamboo is an excellent reforestation crop, even in areas of degraded land on eroded slopes, where farming is not feasible.[2] Clearly, bringing degraded land back to productivity is one of the key stepping stones to meet the increasing

global demand for building materials, and bamboo can play a pivotal role herein.

In terms of versatility as well, bamboo fits perfectly into a bio-based economy. Multiple applications can be met with the same resource: not only can it be used to produce traditional (culm) or engineered building materials (beams, boards, and fibre products), but bamboo is also a perfect feedstock for the production of pulp (paper), fibres (textile), energy (charcoal), purifiers (activated carbon), and several utensils such as chopsticks, baskets, blinds, carpets, etc.

Engineered bamboo products

The industrialization of giant bamboo species such as *Phyllostachys pubescens* (known locally as Moso bamboo) commenced in the 1990s with the production of simple flooring boards made from laminated strips. Since then, the Chinese bamboo industry expanded quickly, adding many new products ranging from flooring, panels, veneer to solid beams. However, because of the limited durability and stability in terms of shrink and swell, applications were initially restricted to indoor areas. Recently, bamboo products suitable for outdoor use have hit the market, made from compressed bamboo strips that were first thermally modified (thermo-density treatment), offering a real alternative for tropical hardwood in outdoor applications. At the time of writing, the Chinese bamboo sector is the leading bamboo industry worldwide, employing 7.75 million people. With an export value of 1,207 million US Dollars, the country is responsible for 65 per cent of worldwide exports in bamboo products, and even for 97 per cent of the bamboo flooring market.[3]

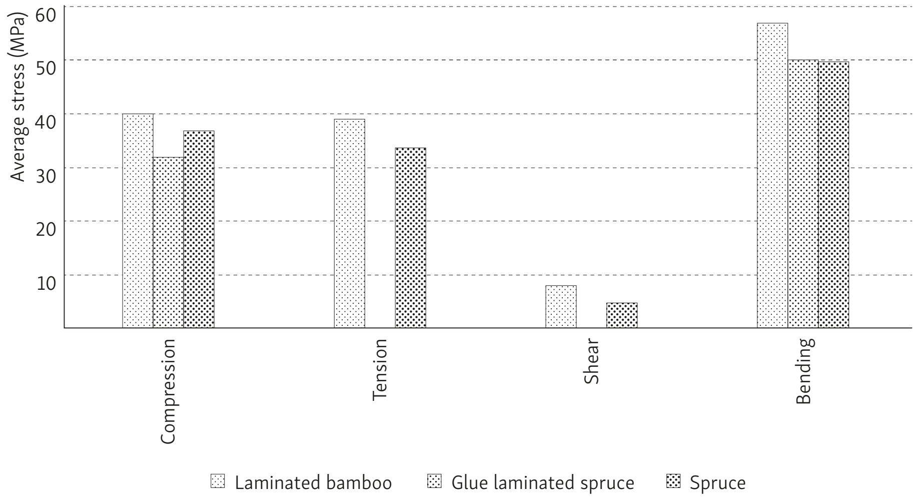
Besides several other processing technologies under development and mimicking engineered wood products such as MDF, OSB, and several other composite products, four main technologies for

◂ Flattened bamboo flooring boards.

▸ Laminated bamboo panels.

◂ Thermally modified bamboo decking.

▸ Strand Woven Bamboo (SWB) beams.



industrially processing bamboo to high-value-added engineered products can be distinguished in China at the moment, as Felix Böck describes in his contribution to this book (p. 72) in more detail:

1) *Flattened bamboo – 850 kg/m³*
Flattening of longitudinally cut bamboo culms by vapour treatment, mainly used for the production of flooring.

2) *Laminated bamboo – 700 kg/m³*
Lamination of strips to produce panels, beams, and flooring boards is the most commonly used technology to develop engineered industrial bamboo products.

3) *Cold-press compression moulding – 1,050–1,100 kg/m³*
Compression moulding of rough bamboo strips with resin (cold-press) to extremely hard and dense boards and panels. These products are often also referred to as Strand Woven Bamboo (SWB) or bamboo scrimber.

4) *Hot-press compression moulding – 1,200 kg/m³*
Same as 3) but based on hot pressing and with additional thermal treatment of input strips to increase durability and stability to enable outdoor use, mainly for cladding and decking.

Whereas most application areas for engineered bamboo were initially decorative, Western architects are increasingly exploring options to use engineered bamboo in (semi-)structural applications such as window frames and small structures such as carports. This applies particularly to laminated bamboo beams (finger-jointed on strip level, divided over the length of the beam for homogeneous composition) because of their relatively low weight compared to Strand Woven Bamboo. However, due to the industrial bamboo industry being at its very beginning, few harmonized structural tests have been executed to date. First results seem promising: studies executed by Cambridge University,[4] following EN 408 for a solar carport for German car manufacturer BMW, show that the applied laminated bamboo beams, impregnated to enable outdoor use, are comparable to and even exceed several important structural properties of typical wood species.

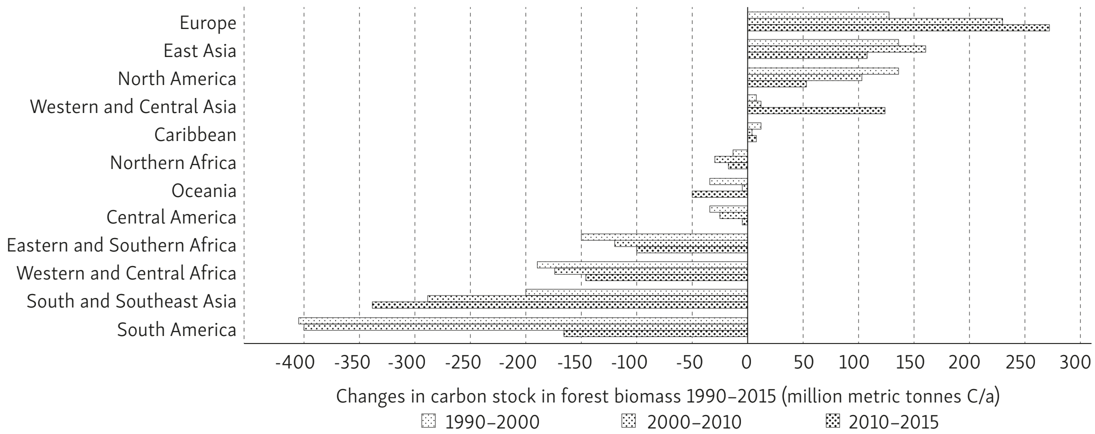
▲ Average stress of laminated bamboo compared to wood.[4]

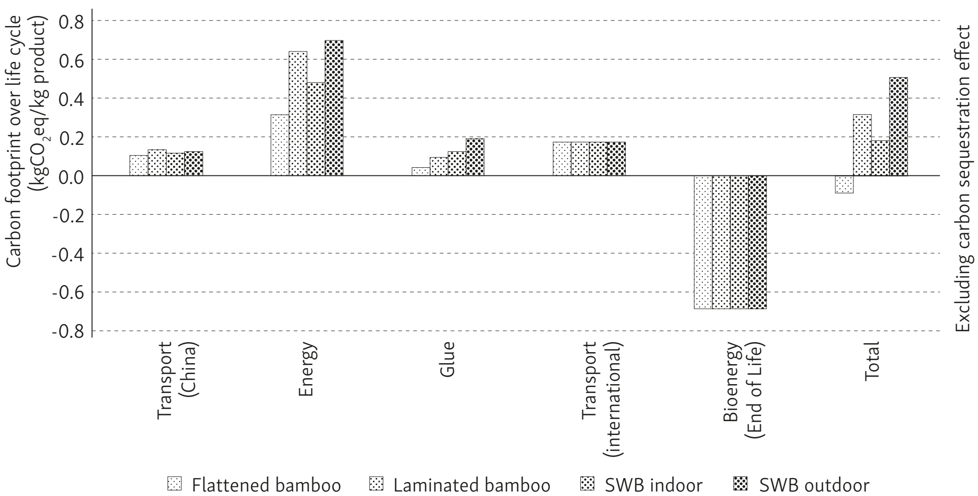
Life-cycle analysis of engineered bamboo products

The role that forests and wood or bamboo products play in the global carbon cycle is constantly gaining attention both positively (forest conservation, afforestation, increasing application in durable products – in particular in Europe and North America) and negatively (deforestation – in particular in tropical regions). It is estimated that around 47 per cent of the world's forest areas have been cleared

▲ **The solar carport for BMW Group in South Africa is constructed with laminated bamboo beams, impregnated to enable outdoor use.**

or degraded to make way for crops, cattle, and infrastructure.[5] The greenhouse gas emissions resulting from deforestation account for 15 per cent of global anthropogenic greenhouse gas emissions. While illegal logging and clear-cutting of tropical forests for hardwood is part of the problem, the sustainable exploitation of tropical forests to produce certified timber (FSC/PEFC) is part of the solution, as it provides an economic incentive to keep the forests intact rather than cutting them down for a onetime use. However, supply is often lower than demand, which is why additional hardwood alternatives are required. This is where engineered bamboo can play an important role. Giant bamboo species such as *Phyllostachys pubescens* are increasingly perceived as tropical hardwood alternatives because of rapid growth, good properties, and wide applicability. However, in a compari-





son with European wood, the relatively long production process and transport distance could disturb the benign environmental profile of bamboo.

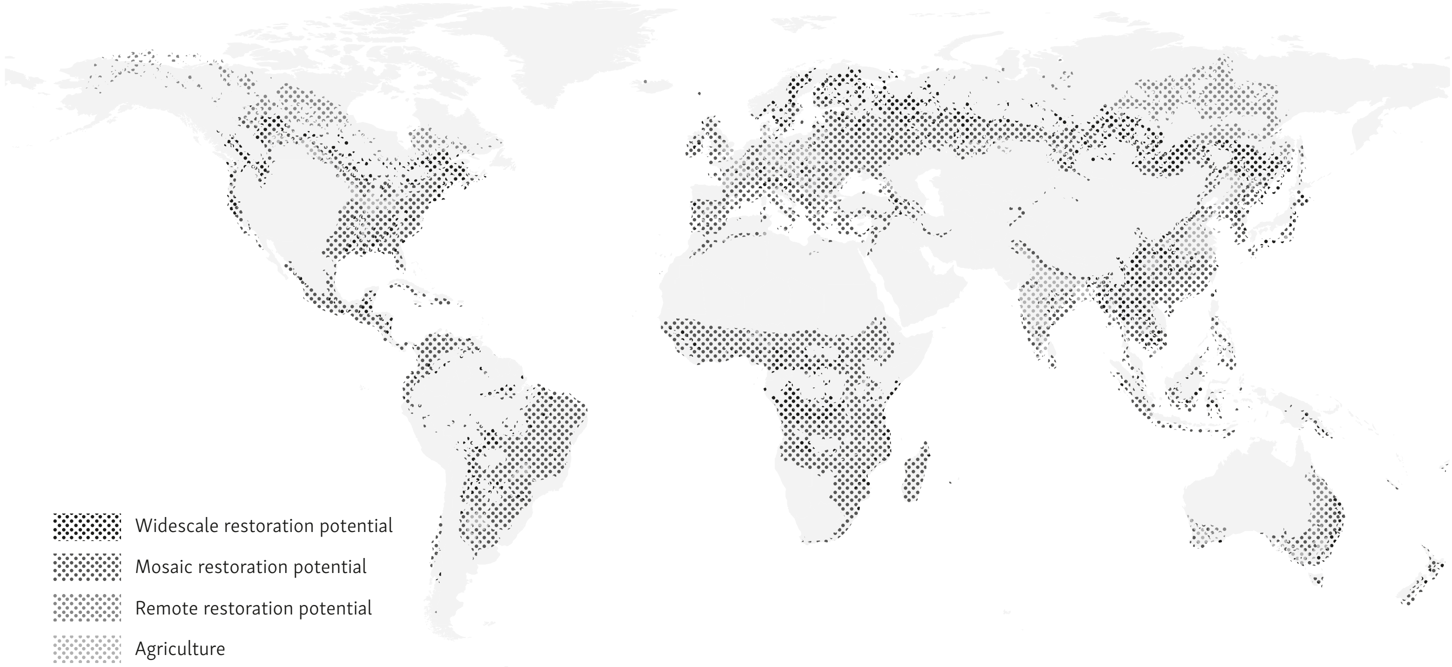
In the following paragraphs, the greenhouse gas balance (carbon footprint) for the four main production technologies as mentioned above are analyzed following a cradle-to-grave scenario, i.e. including the full life cycle of the respective engineered bamboo materials:[6]

Production. To determine greenhouse gas emissions during production, all steps in the chain need to be monitored and calculated, from sourcing the materials at the plantations in China, to processing, treating, and pressing in the manufacturing plant, to final packing and shipping towards their final location (in this case the Netherlands).[7] This cradle-to-gate analysis was based on best-practice production figures from the company MOSO International BV.

End-of-Life credit. Biogenic CO_2 is captured in wood or bamboo during the growth of a tree or culm. This storage remains intact as long as the resulting product exists. When discarded, carbon captured in the plant while growing is being recycled back into the atmosphere during the End-of-Life phase (e.g. composting). Consequently, wood

▲ Trends in carbon stocks in global forests from 1990–2015.

▼ Carbon footprint over life cycle ($kgCO_2eq/kg$ product) for various industrial bamboo products based on different production technologies.



or bamboo products are considered carbon-neutral. However, if such a product is burned in an electrical power plant (a realistic End-of-Life scenario in Western European countries), the system generates electricity or heat, which can replace electricity otherwise generated from fossil fuels, endowing the product with a carbon credit towards a negative carbon footprint.

Preliminary results (excluding carbon sequestration effect). Adding the cradle-to-gate figures to the End-of-Life credit results in the following main emission components in the carbon footprint of engineered bamboo products (range depending on the product assessed):

- energy consumption for processing: 52–63%
- international sea transport: 15–25%
- local transport (truck): 10%
- use of resin: 3% (flattened bamboo) to 16% (outdoor SWB)

Somewhat unexpectedly, it is not the use of glue or the relatively long transport distance to Western markets but the energy consumption in China (an energy mix dominated by coal energy plants) that has the highest portion in the carbon footprint of engineered bamboo products.[8]

Carbon sequestration through landscape restoration credit

As noted above, so far the carbon sequestration effect has not yet been taken into account. Looking at the highest possible aggregation level (Tier 1 and Tier 2), as described in the IPCC Guidelines for National Greenhouse Gas Inventories,[9] and taking into account changing carbon stocks in forests worldwide, it becomes clear that reforestation on degraded land will lead to a net carbon gain. This provides a tremendous opportunity for bamboo. The World Resources Institute[10] has identified two billion hectares suitable for so-called mosaic restoration, integrating forests including bamboo with

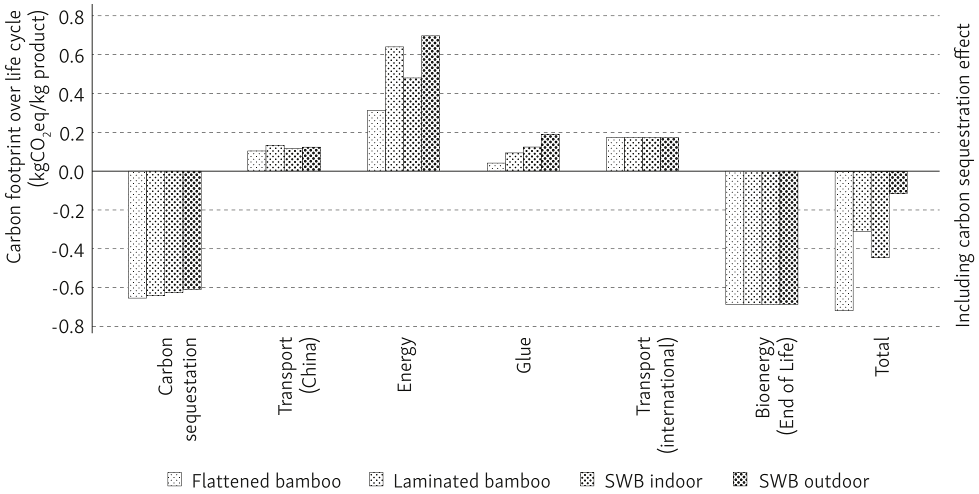
▲ The World Resources Institute (WRI) identified two billion hectares of degraded land globally that offer opportunities for restoration.

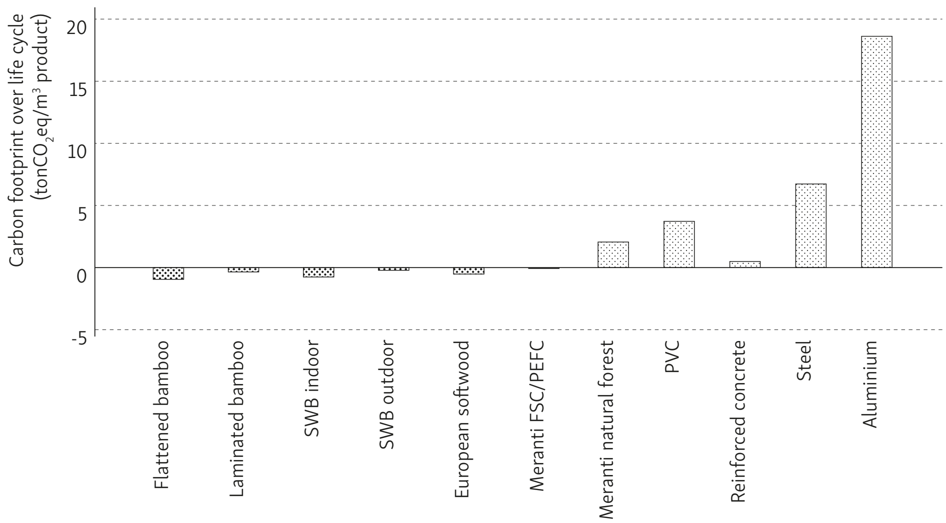
◂ **Typical barren grassland which has been rehabilitated with bamboo over the past years.**

other land uses such as agroforestry and agriculture. By its prevailing overlaps with the natural growth area of giant bamboo, the restoration map shows the important role bamboo can play to make degraded land productive again, with potentially high yields as an additional benefit.

In INBAR's Technical Report No. 35 on the Chinese situation from 2015, the carbon sequestration benefit for reforesting degraded land with bamboo was quantified and allocated to the carbon footprint of engineered bamboo products. Extra demand of engineered bamboo from China has an effect on carbon sequestration which is similar to that of European and North American wood: it leads to a better forest management and an increase in forest or plantation areas.[11] Because of the increased market demand for engineered bamboo products, the annual growth of Moso bamboo areas in China in the year from 2004 to 2011 has been over 5 per cent, mainly occurring on barren wasteland or poor farming grounds through the Grain for Green programme of the Chinese government.

If the carbon sequestration credit from land use change in China is being included in the carbon footprint of the four main engineered bamboo products, the results demonstrate that their carbon footprint can be CO_2-negative, even when applied in Europe. Apparently the credits for bio-energy production during the End-of-Life phase as well as the carbon sequestration as a result of land change both together outweigh the emissions during production in China and shipping the bamboo products to Europe.



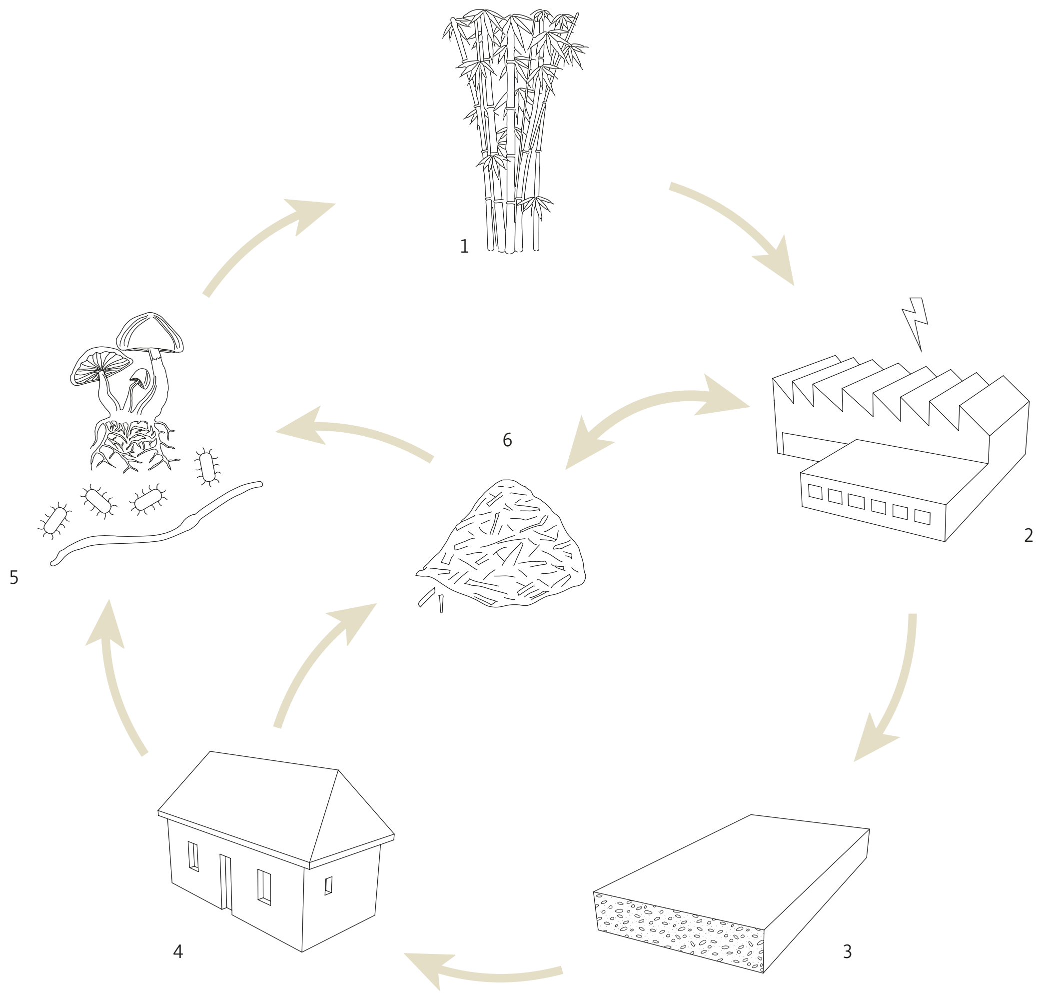


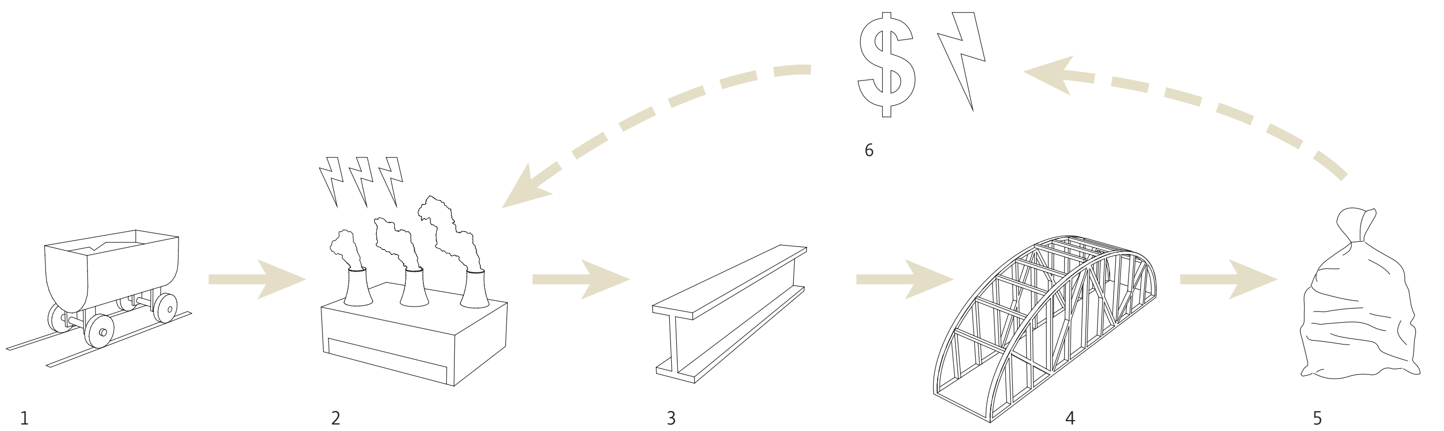
Although the figures do not reflect specific applications – which would include maintenance and material use for required mechanical and functional properties (functional unit) – they give a good indication of how the various materials compare in terms of their environmental impact. This can be used as a basis for more specific calculations for individual applications. Per se, materials pertaining to the biological cycle of the circular economy model have a far lower carbon footprint than energy-intensive materials pertaining to the technological cycle. In terms of carbon footprint, engineered bamboo materials appear to be competitive with sustainably sourced European softwood (which shares a negative carbon footprint as a result of active reforestation and End-of-Life credit for incineration in bio-energy plants), and score better than tropical hardwood, even from sustainably managed plantations (FSC/PEFC). In the case of unsustainably sourced hardwood, including the environmental impact of loss of biodiversity as well as the carbon sequestration debit of clear-cutting, the advantage in favour of engineered bamboo materials becomes overwhelming.

In conclusion, it seems clear that engineered bamboo products with their good mechanical and aesthetical qualities can be a truly sustainable alternative for established building materials, not only from a climate change mitigation perspective (low carbon footprint) but also from the circular economy perspective.[12] If a nutrient from the biosphere can be adequately used as an alternative in the same application as a nutrient from the techno-sphere, it should always be preferred from the sustainability point of view.

▴ Carbon footprint over life cycle ($kgCO_2eq$/kg product).

▾ Carbon footprint over life cycle ($kgCO_2eq/m^3$ building material) for various common building materials.





◂ **The shift from a linear to a closed-loop economy is an economic and ecological necessity.**

1 Resource cultivation
2 Manufacture
3 Cultivated building element
4 Application
5 Biological decomposition
6 Recycling
▴

1 Resource mining
2 Manufacture
3 Mined building element
4 Application
5 Waste
6 Potential Recycling
▾

NOTES

1 Webster, K. (2015), *The Circular Economy – A Wealth of Flows*. United Kingdom: Ellen MacArthur Foundation.
2 Ly, P., Pillot, D., Lamballe, P., de Neergaard, P. (2012). "Evaluation of bamboo as an alternative cropping strategy in the northern central upland of Vietnam: Above-ground carbon fixing capacity, accumulation of soil organic carbon, and socio-economic aspects". *Agriculture, Ecosystems and Environment* 149 (2012) 80–90; Rebelo, C. and Buckingham, K. C. (2015), "Bamboo: The Opportunities for Forest and Landscape Restoration", *Unasylva: Forest and Landscape Restoration* 245 (66).
3 INBAR (www.inbar.int).
4 Sharma, B., Bauer, H., Schickhofer, G., Ramage, M.H. (2016), Mechanical characterisation of structural laminated bamboo. Preceedings of the Institution of Civil Engineers – Structures and Buildings, http://dx.doi.org/10.1680/jstbv.16.00061.
5 Rebelo, C. and Buckingham, K. (2015), "Bamboo: The Opportunities for Forest and Landscape Restoration", *Unasylva: Forest and Landscape Restoration* 245 (66).
6 Readers interested in a complete LCA study (ISO 14040/44) – including several other environmental impact indicators – of these engineered bamboo materials are referred to INBAR Technical Report No 35 and the Environmental Product Declarations of MOSO International: Van der Lugt, P. and Vogtländer J. G. (2015), "The Environmental Impact of Industrial Bamboo Products – Life-cycle Assessment and Carbon Sequestration". *INBAR Technical Report No. 35*. Beijing: International Network for Bamboo and Rattan; Agrodome (2016), *Environmental Product Declaration for MOSO solid panel and beam, MOSO Density, MOSO Bamboo X-treme*. Antwerp: CAPEM. Available online via www.moso.eu/epd.
7 The author used LCA software Simapro v8.04, based on Ecoinvent 3.1 as well as the Idemat TU Delft 2015 and 2016 databases.
8 For a more detailed analysis including points for improvements please refer to Van der Lugt, P. and Vogtländer J. G. (2015), see. 6
9 http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.
10 Minnemeyer, S., Laestadius, L., Sizer, N., Saint-Laurent, C. and Potapov, P. (2011), *A world of opportunity. The Global Partnership on Forest Landscape Restoration*. World Resources Institute, South Dakota State University and IUCN (available at http://pdf.wri.org/world_of_opportunity_brochure_2011-09.pdf).
11 Lou, Y., Yanxia, L., Buckingham, K., Henley, G., Guomo, Z. (2010). "Bamboo and Climate Change Mitigation". INBAR Technical Report No. 32. Beijing: International Network for Bamboo and Rattan.
12 Cascading from high value-added recycling (OSB or particle board) to lower value-added recycling (burn for green energy production) or just biodegradation.

About the Authors and Contributors

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