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◂ **Section of a Strand Woven Bamboo (SWB) product.**

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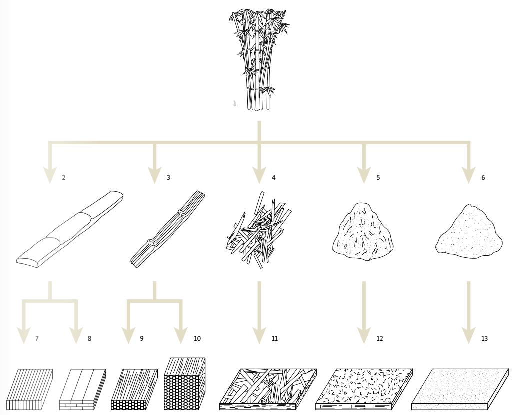
6 Particles
7 Vertical Laminated Board
8 Horizontal Laminated Board
9 Woven Strand Board
10 Parallel Strand Lumber
11 Oriented Strand Board
12 Medium Density Fibre Board
13 Particle Board
▸▸




▾ **Table 1: Comparison of bamboo manufacturers based on their annual production volumes before and after production optimization.**

| Location | Product | Capacity in $m^3/a$ | Optimization & additional investment | Capacity in $m^3/a$ |
|---|---|---|---|---|
| **Factory A – Phase 1 (2012) China** | SWB cold press | 4,000 $m^3$<br>Initial investment: US$ 3.0 million | – Drying prior to pressing<br>– Optimal press parameters<br>No additional investment | 5,060 $m^3$ (2014)<br>Higher volume through moisture control |
| **Factory A – Phase 2 (2014) China** | SWB cold press | 5,060 $m^3$ | – New pre-processing<br>– Optimal drying<br>– Optimal press parameters<br>US$ 110.000 for new machines | 11,200 $m^3$ (2016)<br>Higher volume through pre-processing |
| **Factory A – Phase 2 (2014) China** | SWB hot press | 2,680 $m^3$<br>Initial investment: US$ 3.4 million | – Drying prior to pressing<br>– Optimal press parameters<br>US$ 30,000 (material handling and fans) | 8,000 $m^3$ (2016)<br>Higher volume through moisture control and optimal press programme and material handling |
| **Factory C (2016) South-East Asia** | SBP continuous | 50,000 – 100,000 $m^3$<br>Initial investment: US$ 21.0 million | – New gluing technology<br>– New pressing technology | Planning and commissioning process (2016) |

A study undertaken by the laminated bamboo flooring and strand woven sector has shown that the majority of engineered bamboo manufacturers are using cold-press or discontinuous hot-press technologies with rather low production volumes, averaging 8,000 cubic metres per year.[5]

With an increasing demand of construction materials composed of renewable resources, the option of upscaling the bamboo industry to higher volumes and more industrialized processes is dependent upon new production technologies and optimized management of the material supply. Table 1 indicates opportunities in existing factories which have not yet been fully developed. The example of the participating factories focuses on two major areas of production optimization: firstly, the moisture balance with its impacts on material flow throughout the entire process and secondly, the pre-processing equipment.



Compared to industrial production volumes in the wood industry, a more widespread use of SBP is currently limited by a lack of efficient technological synergies in manufacturing. The potential for reaching larger production volumes with products of a wider variety in terms of sizes and properties is being investigated. The example of Factory C in Table 1 describes a project with the aim to develop and activate a continuous production process for bamboo technologies by fabricating structural products with bamboo-based furnishes, focusing on strands, strips, and fibre mats. As discontinuous press sequences are the dominant production methodology today, this development obviously would increase speed and hence the output of the factory line to an estimated 50,000 to 100,000 cubic metres per year, a significant step compared to today's average 8,000 cubic metres per year.

**Upscaling production processes**
Currently marketed products, be they cutting boards or kitchen tops for an international market, are manufactured with discontinuous press technologies limited by specific dimensions in length of 2.40 to 3.60 metres and a density of 1,000 to 1,200 kilograms per cubic metre. In contrast, continuously produced bamboo-based composite panels/beams with densities closer to the relative density of the raw material (750–875 kilograms per cubic metre) are a new and innovative manufacturing approach, with applications in the construction sector, where high performances, longer spans,

▴ **Industrial bamboo products use a wide variety of extracted raw materials, ranging from strips to fibres to particles.**



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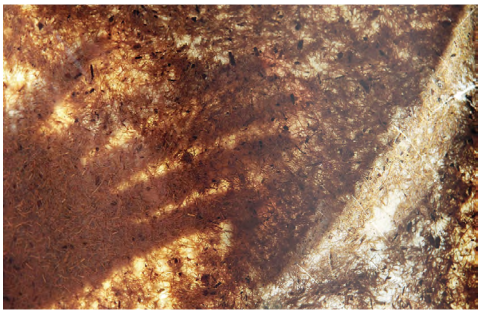
# Biopolymers and Biocomposites Based on Agricultural Residues

Hanaa Dahy and Jan Knippers



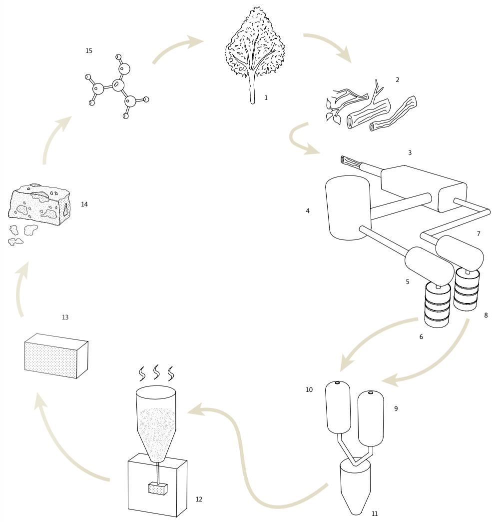
The search for an available, cheap source of renewable, natural fibres as main component in biocomposites and as resource for a number of biopolymers has become an international necessity. Since the late 20th century, global wood consumption has reached a critical level, and the use of crops planted specifically as a source of fibres remains questionable from both social and environmental perspectives. However, the same cannot be said for agricultural residues. Plant lignocellulosic fibres retrieved from agricultural residues such as agro-fibres seem to be a promising alternative resource for efficient biopolymers and biocomposites.

Agro-fibres are available in huge amounts worldwide, mainly as a by-product of the cereal crops harvesting processes. The main interest in annual crop agriculture is the seed itself, the cereal grain, and not its residues left after harvesting. Consequently, huge quantities of agro-fibres accumulate in the fields. While the global majority is being burned to clear space for replanting, a relatively small amount is used in conventional applications such as bedding, energy applications, or straw-bale housing. The huge volume and low density of straw leads to relatively high transportation costs in comparison to wood. Appropriate densification and safe storage of straw fibres could, however, guarantee the fibres' availability throughout the year and decrease transportation costs. Other types of agro-fibres such as maize or sugar cane do not have the same volume problem, yet are unfortunately not prepared for industrial applications after harvesting either – a fact that highlights a still existing waste management problem of the resource.

**▴ TRAshell panels offer different textures and properties depending on the utilized agricultural fibres.**







1 Resource cultivation
2 Tree logs
3 Pre-treatment pulping for e.g. paper industry
4 Saccharification
5 Fermentation
6 Biofuel
7 Chemical processing
8 Chemicals and monomers
9 Chemical processing
10 Fermentation
11 Biopolymer
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13 Biopolymer/biocomposite building element
14 Biological decomposition
15 Biological nutrients

**▴ Plant lignocellulosic fibres retrieved from agricultural residues are a promising alternative resource for efficient bioplastics and biocomposites.**





**◂ The structure involves load-bearing properties of the double-curved skin, both in the load-bearing and bracing processes of the entire system.**

**▸▸ Bio-flexi panels can be twisted and bent accordingly to custom needs, then fixed in their final geometry through veneer layers on both sides.**

For the project, collaborating materials scientists, architects, product designers, manufacturing technicians, and environmental experts were able to develop a new material for façade cladding, which is thermo-formable and made primarily (more than 90 per cent) from renewable resources. Developed by project partner TECNARO within the framework of the research project, ARBOBLEND, a special type of bioplastic granules, can be extruded into sheets which are further processable as needed. They can be drilled, printed, laminated, laser-cut, CNC-milled, or thermoformed to achieve different surface qualities and structures. Various moulded components can be produced. The freeform bioplastic façade functions as a sheet material-based shell structure with additional load-bearing and bracing ring carriers and joists. Contrary to common non-load-bearing façade constructions, this structure involves the load-bearing properties of the double-curved skin in the load-bearing and bracing processes of the entire system.

The goal of this project was to develop a maximally sustainable and durable building material while keeping petroleum-based components and additives to a minimum. It demonstrates the potential of modified bioplastics as a bracing material suitable for exterior applications, as this material adds only a minor load due to its own weight. The façade utilizes a minimized number of points of support or mounting brackets on the structural work behind it. The necessary process of contour milling allows for multiple variations among the moulding components, as identical thermoformed parts can be processed differently using various CNC milling paths. This allows for the cladding of freeform areas with a single moulded component. The plastic waste that results from the CNC milling process is re-granulated and directly returned to the extruding process. At the end of their useful life, the façade sheets can be composted or disposed of almost carbon-neutrally. The ecological audit was completed by the Institute for Water Engineering, Water Quality and Waste Management (ISWA) of the University of Stuttgart. Furthermore, the material's resistance to microbial degradation was determined.

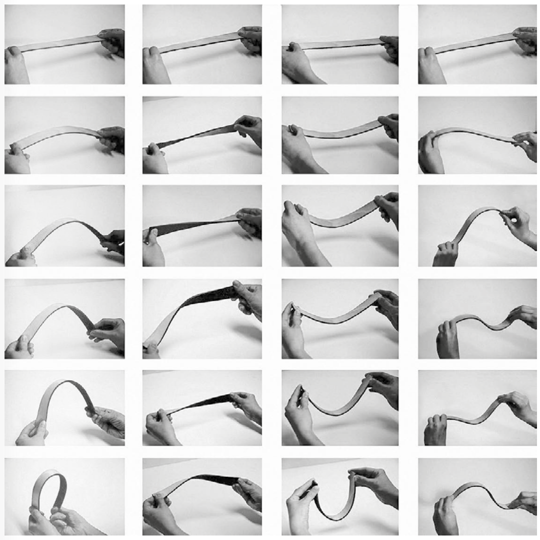
### Bio-flexi high-density fibreboards

The developed material[2] is a flexible, recyclable, and compostable high-density fibreboard (HDF) for architectural applications, manufactured from agricultural residue fibres. The raw agro-fibres, which contribute up to 90 per cent to the final material by weight, are bonded without any pre-chemical modification by an environmentally-friendly, thermoplastic, elastic binder using classic plastic-industry machinery.[3] Subsequent compounding through single- and double-screw extrusion manufacturing processes then produces semi-finished Bio-flexi panels. The high-density fibreboards are suitable for the production of freeform furniture and partitions as well as slip-resistant and shock-absorbent floor covering and underlayment.

The fibreboards can be made from wheat, maize, rice, oat, barley, or rye straw. In the case of rice straw, the fibreboards offer an extra advantage due to the high silicate concentration of up to 20 per cent, which allows the material classification "particularly fire-resistant" according to the German DIN 4102-B1 standard by only adding minimal min-









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