

## 2 Environmental Impact in Eco-costs

### 2.1 Introduction

Although bamboo materials are marketed (and therefore usually also perceived) as environmentally friendly, few quantitative environmental impact assessments using Life Cycle Assessment (LCA) methodology are available for bamboo. The only available studies known to the authors are a study executed by Dr. Richard Murphy (Murphy et al. 2004) and another study executed by the first author for his MSc thesis (van der Lugt 2003) published in various journals (van der Lugt et al. 2003, van der Lugt et al. 2006). The study by Murphy et al. (2004) focuses on the use of bamboo stems (Guadua) in combination with sand/cement (based on the traditional Baharaque technique) as a structural material for social housing in Colombia compared to a similar house executed in masonry and concrete. The environmental impact of the bamboo house was approximately half the impact of the concrete house. Besides the use of the bamboo stem, the study excluded other (industrial) bamboo materials and was based on local consumption of bamboo.

Another LCA study, based on the TWIN 2002 model, was executed by Pablo van der Lugt. Besides the bamboo stem, the study assessed one version of Plybamboo board (10 mm plain pressed Plybamboo). However, part of the input data in the study was not completely reliable, resulting in the new environmental assessments executed in this report. In the next section an introduction will be provided about LCA and the models used in this report to analyze the LCA output data to a single indicator for the environmental impact.

#### LCA

LCA is the commonly accepted methodology to systematically test the environmental impact of a product, service, or in this case, material. Principally, in an LCA, all environmental effects relating to the three main environmental problems (see Table 1.1) occurring during the life cycle of a product or material are analyzed, from the extraction of resources until the end phase of demolition or recycling (from cradle to grave). The LCA-methodology developed by the Centre of Environmental Studies (CML, in Leiden, the Netherlands) was presented in 1992 (Heijungs et al. 1992) and was internationally standardized in the ISO 14040 series.

A basic LCA provides an outcome of different effect scores; a weighing method is not included, and an overall judgment of the environmental impact of products is therefore not possible. Furthermore, a basic LCA is very complicated to understand and

communicate, which is the reason why various additional models have been developed to be used in combination with a basic LCA in order to indicate the environmental burden of products through a “single indicator”. Models to arrive at a single indicator are always subject to discussion, mainly about the weighing method applied in damage based models, but also about the environmental effects included/excluded as well as allocation issues (van den Dobbelsteen 2002). For an overview of available models the reader is referred to van den Dobbelsteen (2004). At Delft University of Technology either the damage based model Eco-indicator 99, or the prevention based model Eco-costs 2007 are used as single indicator models (Vogtländer 2008). In this report the Eco-costs 2007 model is used to identify the environmental burden of the bamboo materials through a single indicator.

It is important to understand that the outcomes of an LCA based calculation should not be perceived as a final judgement, but only as a rough indicator to describe the environmental impact of a product or material. First of all, LCA is a relatively new methodology which is continuously being improved, based on which new models continue to emerge on the market. Secondly, the factors **time** and **place** are not incorporated into an LCA, which means that any LCA based calculation is full of assumptions and estimations which may differ per calculation. For example, for the factor place, even for exactly the same product or material, production data may differ depending on the country of production (e.g. regulations with regard to emissions of production facilities), or the country of consumption (e.g. transport distance). The production context may also differ, which can be best- or worst practice or something in between (e.g. recycling, waste treatment, incorporated at production site), which can cause differences in environmental impact for exactly the same product. Besides these main reasons even more place related aspects may play a role such as the environmental effects of pollution, e.g. some regions are more prone to acid rain than others (Potting 2000).

Furthermore, the time aspect can play a crucial role; if an LCA is based on older data, it may differ considerably from calculations based on current data, based on newer and more efficient production technologies.

Also, due to the fact that the factor time is not included, annual yields of land by renewable materials such as timber and bamboo are not taken into account in an LCA, and are therefore calculated separately in this report in chapter 3.

Summarizing: an environmental impact assessment based on LCA is often lacking specific data and only provides a overview of the environmental impact (in terms of emissions and materials depletion) of a product or material.

### Eco-costs

Eco-costs is a measure to express the amount of environmental burden on the basis of prevention of that burden. It are the costs which should be made to reduce the environmental pollution and materials depletion in our economy to a level which is in

line with the carrying capacity of our earth (de Jonge 2005). As such, the eco-costs are virtual costs, since they are not yet integrated in the real life costs of most production chains (Life Cycle Costs). According to Vogtländer (2008), eco-costs should be perceived as hidden obligations, and should not be confused with external costs which are damage costs and therefore only appropriate for damage based LCA-models. In practice, prevention based- and damage based LCA models seem to give similar results (Vogtländer 2008). The Eco-costs model is based on the sum of the marginal prevention costs during the life cycle of a product (cradle to grave) for toxic emissions, material depletion, energy consumption and conversion of land, and includes labor (the environmental impacts related to aspects such as office heating, electricity and commuting) and depreciation (e.g. vehicles, equipment, premises) related to the production and use of products (de Jonge 2005, Vogtländer 2001). The advantage of eco-costs is that it is expressed in a standardized monetary value which can be easily understood, and may be used in the future for the establishment of the right level of eco-taxes and/or emission rights. Although calculation of the prevention based eco-costs is not easy, the calculation is feasible and transparent compared to damage based models which have the disadvantage of extremely complex calculations with subjective weighting of the various aspects contributing to the overall environmental burden (Vogtländer 2001). For further examples of the differences between calculations in prevention- and damage based models the reader is referred to the [ecocostsvalue.com](http://ecocostsvalue.com) website (Vogtländer 2008).

### **System Boundaries and Data Collection for LCA**

Since almost every product or material goes through different production activities with different parameters, it is important to make very clear in any LCA based calculation which aspects are and which aspects are not included in the data used for the calculation. Only if these system boundaries are clear, results can be compared with other LCA based calculations, which are based on similar boundaries. In this Subsection the most important assumptions and system boundaries used for this environmental impact assessment are provided, as well as the procedure and sources for data collection and -processing for the assessment.

### **Points of Departure and Basic Assumptions**

The environmental impact assessment was executed for various bamboo materials (Plybamboo in several variations, stem, fibers<sup>10</sup>, Strand Woven Bamboo and Bamboo Mat Board). Because the aim of this study is to test the environmental sustainability of bamboo compared to wood and especially tropical hardwood, the bamboo materials were compared to relevant wood species. In the Eco-costs 2007 database, available via [www.ecocostsvalue.com](http://www.ecocostsvalue.com), the eco-costs of various materials, including various wood species, are provided. This Eco-costs database provides the single indicators (i.e. eco-

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<sup>10</sup> Only assessed in a qualitative manner due to lack of data for a complete LCA.

costs) derived from Life Cycle Inventory (LCI) databases such as Ecoinvent and IDEMAT. The doctorate thesis of Pablo van der Lugt was based on LCIs of Ecoinvent version 1; this report is based on LCIs of Ecoinvent version 2 (available since December 2007). The IDEMAT database is particularly strong in LCIs of wood. This report uses the IDEMAT2008 data, based on the Ecoinvent version 2 LCIs.

The environmental impact assessment for bamboo was based on a so called “Cradle to Site” scenario, which includes all environmental effects until the point of use of the material (Hammond and Jones 2006). Although this is different from a Cradle to Grave scenario, which includes the use and end-of-life phase of a product or material, it is assumed that there are no major differentiating factors between bamboo and wood in these phases, because of the similar life span and chemical composition (same dump or recycle mechanisms deployed) of both materials in the applications in which bamboo was compared with wood (Functional Unit, see below). Thus, an environmental impact assessment based on a Cradle to Site scenario should suffice to compare the eco-costs of bamboo with wood. The assessment for bamboo was based on their use as a semi finished material (excluding additional finishing such as lacquering) in various applications in the Netherlands. From the production side the calculation was based on the use of bamboo resources (Moso species) derived from sustainably managed plantations<sup>11</sup> in the Anji region (province Zhejiang) in China, for which no primeval forests were recently cut.

Finally, for the comparison of material alternatives in a certain function, a general basis of comparison needs to be determined. This basis is called the “Functional Unit” (ISO 2006, van den Dobbelsteen 2002). For a correct comparison, the Functional Unit (FU) is of vital importance: sizes of the alternatives are determined by their technical and functional requirements. Depending on the application these requirements may differ considerably. For example, for a supporting beam, strength might be the crucial criterion while for a floor, hardness and aesthetics might be the most important requirements that should be met, that determine the amount of material required. In the several sections in this chapter for the calculation of each material the FU will be introduced in detail.

### **Data Collection and Analysis**

Evidently, the key to any LCA based calculation is to acquire reliable data about the production process of the products or materials assessed. For this reason extensive inquiries were made in summer 2007 through questionnaires and telephone interviews with the Mr. René Zaal, director of Moso International BV, and the suppliers of Moso International in China (DMVP and Dasso, Mr. Xia; Hangzhou Dazhuang Floor Co, Ms. Isabel Chen). Furthermore, data used for the LCA calculation executed by the first author in an earlier study (van der Lugt et al. 2003) based on the TWIN 2002 model,

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<sup>11</sup> It should be noted that most Chinese plantations originally used to be natural forests from which other vegetation has been removed. This initial loss of biodiversity is not taken into account in this calculation.

was also used as input for an adjusted calculation for the stem based on production in China instead of in Costa Rica (production region for the earlier LCA study by the first author). During the environmental impact assessment of the bamboo materials for each production- and transport process step the environmental effects were noted (mostly based on energy consumption and addition of chemicals), and translated into eco-costs by the second author of this study, Dr. Joost Vogtländer, architect of the Eco-costs model, who assisted the first author in processing the data. The density used in the calculations for all alternatives was based on Wiselius (Wiselius 2001) and Ashby and Johnson (2002). The outcomes of the eco-costs calculation for the bamboo materials, based on the added sum of all process steps, was compared with the data for various alternatives mostly in wood.

Below, the results of the environmental impact assessments for the various bamboo materials will be presented and compared to various wood based materials. In appendix A all the activities calculated during the production chain (Cradle to Site scenario) are covered for the various bamboo materials in various forms (e.g. carbonized, bleached, etc.), including all the assumptions made during this process, which shows the complexity of the data collection and -analysis procedure during environmental impact assessments.

## 2.2 Wood Based Materials

The eco-costs per kilogram of various wood species and wood based panels are represented in Table 2.1. Data was derived from the Eco-costs 2007 database (Vogtländer 2008), which largely derives its data from The Life Cycle Inventories (LCIs) of the Ecoinvent version 2.0 database and IDEMAT 2008 database (DfS 2008). For wood the data is based on production figures of sawn timber in dried state ready for sale in wholesale outlets in the Netherlands, often dried and processed into sawn timber in the Netherlands (based on a Cradle to Site scenario, thus including all processing and transport steps). The eco-costs per kilogram figures for wood from the databases are based on averages of the most commonly used production scenarios of the wood for consumption in the Netherlands. For example, Beech for consumption in the Netherlands is mostly produced in Germany, Belgium and Luxemburg based on which the average transport distance is calculated in the IDEMAT database (DfS 2008). For more details is referred to the online databases at [www.ecocostsvalue.com](http://www.ecocostsvalue.com).

From Table 2.1 it can be seen that due to material depletion, the differences in eco-costs between the various wood species are considerable. The eco-costs for material depletion are based on degradation of biodiversity, caused by the conversion of land (i.e. the difference in biodiversity before and after the harvest) (Barthlott and Winiger 1998). In the case of a sustainably managed plantation, material depletion is zero because the biodiversity (species richness) remains the same, resulting in zero eco-costs.

Since most wood from Europe comes from sustainably managed plantations nowadays, the material depletion for European wood is not much of an issue.

Category	Material/species	Data source	Total Eco-costs (€)/kg, including material depletion <sup>12</sup>
Wood	Scots Pine	Idemat 2008 database	0.05
	European Beech	Idemat 2008 database	0.04
	Walnut	Idemat 2008 database	0.06
	Teak (natural forest; RIL)	Idemat 2008 database	7.67 (7.46)
	Teak (FSC certified)	Idemat 2008 database	1.70 (1.49)
	Teak (plantation)	Idemat 2008 database	0.21
	Poplar	Idemat 2008 database	0.03
	European Oak	Idemat 2008 database	0.04
	Robinia	Idemat 2008 database	0.05
	Azobé (natural forest; RIL)	Idemat 2008 database	3.96 (3.87)
	Azobé (FSC certified)	Idemat 2008 database	0.86 (0.77)
	Azobé (plantation)	Idemat 2008 database	0.09
Wood based board material	Particle board, indoor use	Eco-invent 2.0 database	0.13
	Medium density fibreboard	Eco-invent 2.0 database	0.17
	Fibreboard hard	Eco-invent 2.0 database	0.16
	Plywood, indoor use	Eco-invent 2.0 database	0.23
	Plywood, outdoor use	Eco-invent 2.0 database	0.37
Note: the wood is dried lumber, four sides sawn and planed, in the Antwerp-Rotterdam-Area. Wood based material is at the gate of the production plant			

In the case of wood deriving from tropical forests (see for example Teak and Azobé in Table 1.1) the situation is different because of the high biodiversity of the source. Teak comes from South East Asia, where the biodiversity is very high (resulting in eco-costs of 13,2 € per m<sup>2</sup> of land). Azobé comes from Cameroon, Gabon and Nigeria, where the average biodiversity is also high (resulting in eco-costs of 11,3 € per m<sup>2</sup> land).

In the calculations Reduced Impact Logging (RIL) is assumed (Rose 2004), resulting in 50% loss of eco-value in a tropical forest. With a yield of 25 m<sup>3</sup> initial harvest per hectare, resulting in 14 m<sup>3</sup> dried lumber (four sides sawn and planed beams), the eco-costs of land-use of Azobé is 3,87 €/kg; see Table 2.1. Note that the specific gravity is quite different: Teak 630 - 680 kg/m<sup>3</sup>, Azobé 940 - 1100 kg/m<sup>3</sup>. For details of this calculation, and calculations of other wood types, see Vogtländer (2008).

As a result, tropical hardwood RIL harvested from a natural forest is not competitive with European grown wood with respect to the eco-costs/kg.

<sup>12</sup> Contribution of material depletion in brackets; if none mentioned, the material depletion is zero (wood from sustainably managed plantations).

Table 2.1: Eco-costs per kilogram of various wood (based) materials

Under the FSC certification scheme, the compensation costs because of material depletion are considerably lower. The FSC certification scheme guarantees - to some extent - a sustainable and socially responsible chain of custody when harvesting, transporting and processing trees into sawn timber. FSC practices, however, differ from country to country; local customs are adhered to.

Less than 40% of FSC wood is harvested from plantations (FSC 2008). The rest is harvested from natural forests. RIL logging is more or less guaranteed, and one may hope that areas with high biodiversity are preserved.

Under the assumption that 40% of FSC wood is logged at plantations, and under the assumption that the higher biodiversity areas are preserved - resulting in 2/3 less degradation of biodiversity - Vogtländer (2008) assumes a 10% loss in eco value caused by harvesting FSC wood (instead of a 50% loss assumed for RIL), corresponding with 0.77 €/kg for Azobé (see Table 2.1).

For more details of the impact in eco-costs of all other activities along the production chain based on a Cradle to Site scenario for the various wood species the reader is referred to the IDEMAT2008 data and the excel file Ecocosts Calculations on Wood at [www.ecocostsvalue.com](http://www.ecocostsvalue.com) tab FAQs, question 1.7.

Note that the eco-costs of wood from plantations are mainly determined by the eco-costs of transport, where the eco-costs of transport by sea is approx. 0.0052 €/tkm, and the eco-costs of transport by road is approx. 0,034 – 0,039 €/tkm.

In the next sections, the eco-costs for the various wood based materials will be compared to the results of the eco-costs for the bamboo based materials for that typical function.

## 2.3 Plybamboo

Plybamboo materials exist in many sizes, colors, layers and patterns. The most common differences are the thickness, ranging from 0.6 mm (veneer) to 40 mm (5-layer Plybamboo panel), the texture (plain pressed or side pressed) and the color (the most commonly used colors are bleached and carbonized; see Figure 2.1).

Figure 2.1: Plybamboo is available in various colors, textures and sizes; in the left picture Plybamboo flooring (from left to right: bleached side pressed, bleached plain pressed and carbonized plain pressed) is depicted, in the right picture a sample of a 3-layer carbonized Plybamboo panel is shown



The environmental impact of 3-layer Plybamboo board (bleached and carbonized), 1-layer Plybamboo board (bleached and carbonized, plain pressed and side pressed) and veneer (bleached and carbonized, plain pressed and side pressed) were calculated. The standard dimensions of most Plybamboo boards are 2440 mm (length) × 1220 mm (width), which was used as a base element for the eco-costs/kg calculations for Plybamboo. In appendix A all the calculated activities during the chain of these Plybamboo materials are presented, including all the assumptions made during this process. The results of these elaborate calculations in appendix A are depicted in the form of the final eco-costs/kg of the various Plybamboo boards in the following tables.

Table 2.2: Eco-costs per kg of 3-layer Plybamboo board

Product	Eco-costs (€)/kg
3-layer bleached Plybamboo board	0.354
3-layer carbonized Plybamboo board	0.395

Table 2.3: Eco-costs per kg of 1-layer Plybamboo board in several variations

Product	Eco-costs (€)/kg
1-layer plain pressed Plybamboo board (bleached)	0.333
1-layer side pressed Plybamboo board (bleached)	0.358
1-layer plain pressed Plybamboo board (carbonized)	0.374
1-layer side pressed Plybamboo board (carbonized)	0.398

Product	Eco-costs (€)/kg
Plain pressed veneer (bleached)	0.78
Side pressed veneer (bleached)	0.49
Plain pressed veneer (carbonized)	0.88
Side pressed veneer (carbonized)	0.55

Table 2.4: Eco-costs per kg of Plybamboo veneer in several variations

Please note that these figures do not say a lot yet. Only when a material is used as an element in a product in which it fulfils a function (the so called Functional Unit, FU), the required amount of kilograms of the material can be calculated, and it can be compared with other materials based on the eco-costs per FU. Depending on the form or density of the material, this may result in completely different outcomes with respect to the eco-costs. For example, while the eco-costs per kilogram of steel at 0.487 €/kg (Vogtländer 2008) is almost as high as for the Plybamboo boards, because of the high density of steel (7850 kg/m<sup>3</sup>), a lot more kilograms of material will most likely be required (depending on the function). The potentially confusing character of the eco-costs/kg is also the reason why the results for the various Plybamboo materials were represented in separate tables above. Later in this chapter the eco-costs for bamboo materials for several FUs will be compared to other materials.

However, analyzing the production process steps (see appendix A) that have led to the eco-costs/kg figures can already provide insight into the contribution of each process step to the environmental impact for each individual material. This process step analysis can pinpoint causes of the difference in eco-costs/kg for bleached and carbonized Plybamboo material (see Figure 2.2), and the difference in side pressed and plain pressed Plybamboo (only applicable for the 1-layer board).

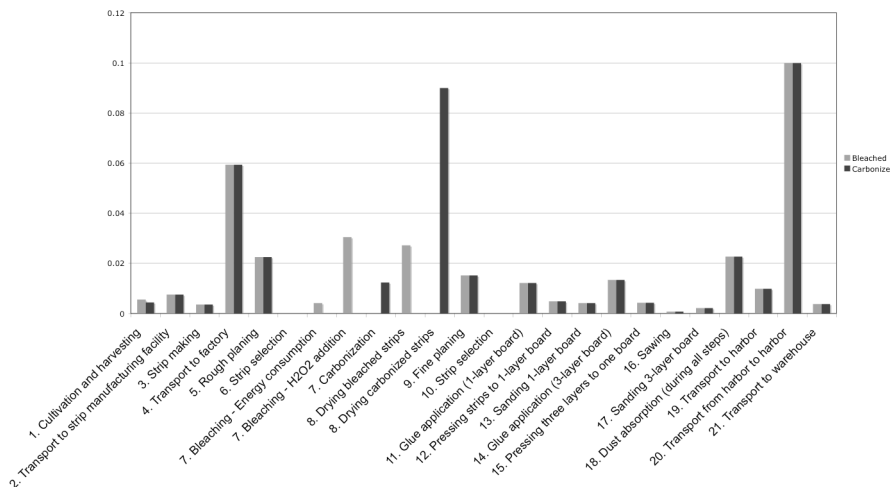


Figure 2.2: Environmental impact in eco-costs (€/kg) of the various process steps during the production and transport of 3-layer Plybamboo board to the Netherlands

From Figure 2.2 some conclusions can be drawn. First of all, the Figure shows that there are many process steps that bamboo as a resource has to go through until it ends

up in the final board material in the warehouse in the Netherlands. Secondly, the Figure shows that transport (dispersed over various process steps) has a large influence on the environmental impact of Plybamboo. For precise numbers and percentages of each process step, the reader is referred to the Tables in appendix A. Finally, Figure 2.2 tells us that the preservation and drying phase also has a relatively large impact on the eco-costs for Plybamboo, and is also the differentiating factor causing the difference in eco-costs per kilogram between the bleached and carbonized version of Plybamboo. Whereas the addition of  $H_2O_2$  has a relatively large impact on the environmental impact of bleached Plybamboo, for carbonized Plybamboo the longer and more drying cycles required (total of 240 hours) levels out the smaller environmental impact carbonization has as a preservation method<sup>13</sup>. Similarly, the differences between plain pressed and side pressed Plybamboo can be assessed, which is differentiating in the case of a 1-layer board (see Table 2.3 above), caused by the larger amount of glue required in side pressed bamboo (for details see Tables A3-A7 in appendix A).

Based on these kinds of analyses, Plybamboo material producers can see where they should focus their attention if they want to lower the environmental damage the production and transport of their material inflicts, see also footnote 13. This can be done, for example, by finding more environmentally friendly preservatives/chemicals for bleaching, or finding less energy consuming ways to dry carbonized bamboo strips (e.g. solar powered drying chamber; see Figure 2.3 for a low-cost example used in Colombia).



Figure 2.3: Low cost solar powered drying chamber for bamboo strips in Colombia developed by Jörg Stamm

### Eco-costs per FU

As mentioned above, the eco-costs/kg figures of Plybamboo do not say a lot compared to other materials; it is only when they are used in a certain application - which determines the required amount of kilograms per material to satisfy needs in this FU -

<sup>13</sup> It should be noted that, according to the material importer (Moso International), the second drying cycle for carbonization (see also appendix A) is not necessary. As a result, the material producer intends to shorten the drying time, cutting down the eco-costs. This case shows the practical use of LCA for improving the environmental sustainability.

that the eco-costs of materials can be properly compared. Usually a material will be deployed in an application in which the specific advantages of the material can serve as an added value. The competitive advantages of Plybamboo lie in the hardness and aesthetic qualities of the material, which can be utilized in applications such as flooring or tabletops. Compared to most wood based materials in these applications, there will not be many differences in volume used to satisfy needs for the application. Since the initial PhD research of Pablo van de Lugt focused on the interior decoration sector, Plybamboo was compared with various wood materials for a piece of furniture, e.g. in the function of a tabletop (see an example in Figure 2.4). Later in this Section Plybamboo is compared in a lounge chair with wood alternatives based on its bendability.



Figure 2.4:  
Plybamboo  
board used as a  
tabletop

### Tabletop as FU

Depending on the market segment targeted, different wood based alternatives can be used as tabletop. In general the aesthetic properties are a most important product attribute for wood species selection in this application. Furthermore, wood species are usually used that are sufficiently hard (so deciduous trees like Pine are not eligible), and combine this feature with a warm color and beautiful distribution of rays, such as European Oak, Teak, or Walnut. The size (and especially thickness) of the tabletop will usually be chosen based on dimensions of the semi finished material to facilitate an efficient production. For this particular environmental assessment will be calculated with a dimension of the tabletop of  $1220 \times 1220 \times 20$  mm. In the case of medium to high end markets, customers tend to prefer a solid wooden tabletop. To reduce costs in low end markets, producers usually opt for the use of a wood based board, such as MDF, chipboard, hardboard or plywood, as carrier, and a top layer of veneer with nice aesthetic properties as mentioned above (European Oak, Walnut and Teak). Based on these parameters the eco-costs per FU were calculated for both the medium-high end market (based on solid material) and low end market (based on a wood based board material as carrier); see the Tables below. For Plybamboo it was calculated with the eco-costs/kg of the 3-layer panel. In the final column the eco-costs/FU of the most environmentally friendly 3-layer panel (bleached) was compared to the various wood

alternatives. Note that in the calculation, the life span, maintenance and end-of-life scenario is assumed not to be differentiating for the various alternatives in this application.

Material	Density (kg/m <sup>3</sup> )	Eco- costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
3-layer Plybamboo carbonized	700	0.395	20.9	8.26	112%
3-layer Plybamboo bleached	700	0.354	20.9	7.40	100%
European Oak	700	0.04	20.9	0.84	11%
Walnut	690	0.056	20.5	1.15	14%
Teak (natural forest; RIL)	650	7.67	18.8	144	1950%
Teak (FSC certified)	650	1.70	18.8	32.0	432%
Teak (plantation)	650	0.21	18.8	3.95	53%

Table 2.5: Eco-costs per tabletop of 1220 × 1220 × 20 mm (0.0298 m<sup>3</sup>) based on solid material

The eco-costs/kg numbers for wood relate to sawn timber. The eco-costs/kg for veneer production need to be adjusted, since veneer production has higher material losses due to the thin character of the material. As calculated in appendix A material input during the production of the highest quality (zero defect), bamboo veneer is due to these material losses 1.38 times (side pressed bamboo) to 2.35 times (plain pressed bamboo) higher compared to the 1-layered Plybamboo board. For the production of the highest quality wood veneer it is assumed that material input is twice as high compared to the production of sawn timber, which means that the eco-costs/kg are doubled compared to the eco-costs/kg for sawn timber in Table 2.5. To calculate the eco-costs for a tabletop for the low end market based on veneer and an inexpensive wood based board as carrier (see Table 2.8), first the eco-costs for the veneer and wood based board are calculated separately (see Tables 2.6 and 2.7). For the veneer calculation in the final column, the eco-costs of the various alternatives are compared with the bamboo alternative most often used in practice (side pressed carbonized). For the carrier board calculation and the total tabletop (carrier + veneer) in the final column, the ratio compared to the most environmental friendly bamboo material (3-layer bleached Plybamboo, see Table 2.5 above) is depicted.

Material	Density (kg/m <sup>3</sup> )	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
Plain pressed veneer (bleached)	700	0.78	0.60	0.47	141%
Side pressed veneer (bleached)	700	0.49	0.60	0.29	88%
Plain pressed veneer (carbonized)	700	0.88	0.60	0.53	159%
Side pressed veneer (carbonized)	700	0.55	0.60	0.34	100%
European Oak	700	0.08	0.60	0.05	15%
Walnut	690	0.112	0.59	0.066	19%
Teak (natural forest; RIL)	650	15.3	0.56	8.5	2500%
Teak (FSC certified)	650	3.4	0.56	1.9	558%
Teak (plantation)	650	0.42	0.56	0.24	71%

Table 2.6: Eco-costs per 1220 × 1220 × 0.6 mm (0.00086 m<sup>3</sup>) veneer sheet used for a tabletop

Material	Density (kg/m <sup>3</sup> )	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
MDF	750	0.17	22.35	3.80	51%
Plywood (Indoor)	600	0.23	17.9	4.12	56%

Table 2.7: Eco-costs per 1220 × 1220 × 20 mm (0.0298 m<sup>3</sup>) of wood based board material used as carrier in a tabletop

Material (carrier + veneer)	Eco-costs (€)/FU	Eco-costs/FU (ratio)
MDF + Plain pressed veneer (bleached)	4.27	58%
MDF + Side pressed veneer (bleached)	4.09	55%
MDF + Plain pressed veneer (carbonized)	4.33	59%
MDF + Side pressed veneer (carbonized)	4.14	56%
MDF + European Oak	3.85	52%
MDF + Walnut	3.87	52%
MDF + Teak (natural forest; RIL)	12.3	166%
MDF + Teak (FSC certified)	5.7	77%
MDF + Teak (plantation)	4.04	55%
Plywood + Plain pressed veneer (bleached)	4.59	62%
Plywood + Side pressed veneer (bleached)	4.41	60%
Plywood + Plain pressed veneer (carbonized)	4.65	63%
Plywood + Side pressed veneer (carbonized)	4.46	60%
Plywood + European Oak	4.17	56%
Plywood + Walnut	4.19	56%
Plywood + Teak (natural forest; RIL)	12.6	170%
Plywood + Teak (FSC certified)	6.0	81%
Plywood + Teak (plantation)	4.36	59%

Table 2.8: Eco-costs per tabletop consisting of a 1220 × 1220 × 20 mm carrier finished with veneer (accumulation of Tables 2.6 and 2.7)

In Figure 2.5 the results of Table 2.5 (solid material) and Table 2.8 (veneer on carrier) are visually represented. In the Figure alternatives based on a wood based board material and a veneer carrier (low end market) are depicted in black, while the solid wood alternatives are depicted in gray and the solid bamboo alternatives in light gray.

From Figure 2.5 it becomes immediately clear that from an environmental point of view the use of tropical hardwood, even FSC, has a very large environmental burden, and should preferably be avoided. Since the bamboo assessed in this evaluation was

derived from a sustainably managed plantation, it is fair for the comparison with wood to focus on the eco-costs figures for wood also sourced from a sustainably managed plantation. To better understand nuances between alternatives sourced from sustainably managed plantations, the environmental costs of alternatives from FSC certified Teak and Teak from natural forests were excluded in Figure 2.6.

Figure 2.5:  
Eco-costs for a  
1220 × 1220 ×  
20 mm tabletop  
for various  
wood- or  
bamboo based  
alternatives  
(including  
alternatives  
harvested in  
natural forests)

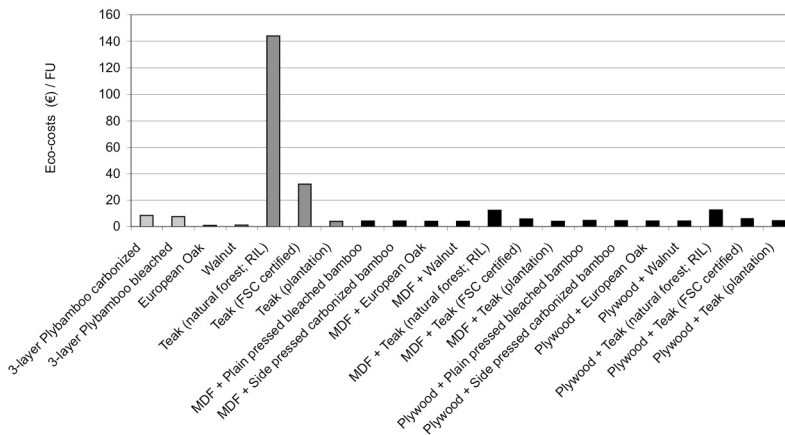
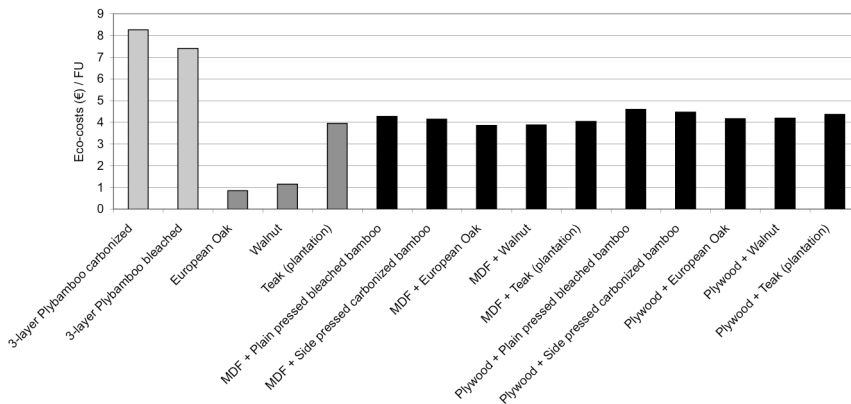


Figure 2.6:  
Eco-costs for a  
1220 × 1220 ×  
20 mm tabletop  
for various  
wood- or  
bamboo based  
alternatives  
(excluding  
alternatives  
harvested in  
natural forests)



Several conclusions can be drawn from Figure 2.6.

First of all, it can be seen that tabletops, made from solid wood which is grown and harvested in the same continent as where it is used (Walnut, European Oak), have by far the lowest environmental burden (14% respectively 11% compared to 3-layer bleached Plybamboo, see Table 2.5). If this solid wood is derived from other continents far away, as in the case of plantation grown Teak from South-East Asia & Brazil, the environmental impact is higher than for the other alternatives (excluding Plybamboo).

If MDF is chosen as carrier, the environmental impact is three times as high as for solid wood grown in Europe, but still more than twice as low as for the 3-layer Plybamboo alternatives. If Plywood is chosen as carrier, the situation is similar.

Figure 2.6 shows that, in terms of eco-costs, it is better to use bamboo veneer on a wood based board as carrier, than Plybamboo in solid form<sup>14</sup>.

To better understand the differences in eco-costs between the various alternatives one should analyze and compare the environmental impact of the various production process steps for bamboo (see Figure 2.2 for Plybamboo) and for wood (see the IDEMAT database (DfS 2008)). In Figure 2.2 it was found that for Plybamboo, transport and drying (carbonized version) or bleaching through  $H_2O_2$  & drying (bleached version) contributed most to the eco-costs. Depending on the species and location of sourcing for various wood species, material depletion (especially from natural tropical forests; see above), transport and drying are the process steps which are most harmful in terms of eco-costs for wood.

It should be noted that sea transport from China to the Netherlands has a large impact (25-28%; see Tables A1 and A2 in appendix A) on the environmental burden of Plybamboo. If Plybamboo is used locally (in China) the eco-costs will therefore be considerably lower, and Plybamboo might become increasingly competitive in terms of eco-costs with locally grown wood species.

### Lounge Chair as FU

During the design project “Dutch Design meets Bamboo” (for more info see van der Lugt 2007), it was found that the bendability can also be acknowledged as a competitive advantage for Plybamboo (see for example lounge chair designed by Tejo Remy and René Veenhuizen in Figure 2.7). Therefore, this chair was chosen as another FU to compare the eco-costs of bamboo with wood.

The chair consists of seven slabs of 1-layer carbonized, side pressed Plybamboo (three slabs of approximately  $2.25 \times 0.15 \times 0.005$  m, four slabs of  $1.25 \times 0.15 \times 0.005$  m; in total 0.0088 m<sup>3</sup> of material). For bending, Beech is usually chosen as the most appropriate wood species. As an additional alternative plywood topped with a veneer layer of an aesthetic wood species (e.g. Walnut) may be used in this application. For both the Beech and plywood alternatives it is assumed that the same volume of material is required as for Plybamboo. In Tables 2.9 and Figure 2.8 the eco-costs/FU for Plybamboo and the various alternatives are represented.

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<sup>14</sup> Please note that additional eco-costs of adhesives required to glue the veneer onto the wood based carrier were not taken into account in this calculation.

Figure 2.7:  
Bamboo chair  
by Tejo Remy  
and René  
Veenhuizen

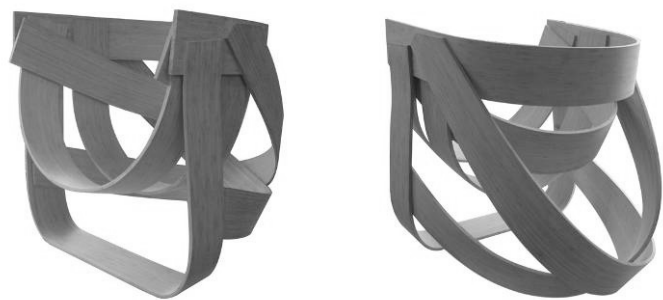
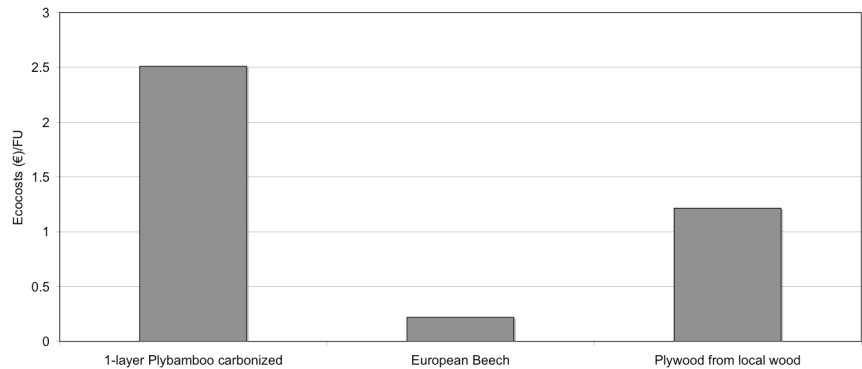


Table 2.9: Eco-costs per year for 1-layer Plybamboo (carbonized) and wood alternatives used in the bended lounge chair

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
1-layer Plybamboo carbonized	700	0.398	6.16	2.45	100%
European Beech	670	0.037	5.90	0.22	8.9%
Plywood (local wood, excluding veneer layer)	600	0.23	5.28	1.21	49%

Figure 2.8:  
Eco-costs per year for 1-layer Plybamboo and wood alternatives used in the bended lounge chair



From Figure 2.8 it becomes clear that also in this application the Plybamboo alternative scores worse in terms of eco-costs compared to relevant wood alternatives for this particular application. Here also applies that the eco-costs for Plybamboo will be lower if it is not exported and sea transport eco-costs can be avoided (24.9% for carbonized side-pressed 1-layer Plybamboo board; see Table A6 in appendix A).

## 2.4 Stem

The bamboo stem, used as input for the production of Plybamboo in the previous calculation, can also be used directly as a material in various applications. Therefore, in this environmental impact assessment the bamboo stem was also compared with

alternatives in wood. The environmental costs per kilogram during the production and transport of the bamboo stem were calculated for a 5.33 m long bamboo stem from the Moso species. For the calculations the reader is referred to appendix A. In Table 2.10 the eco-costs per kilogram of a Moso stem are depicted. In Figure 2.10 the contribution of each process step to the eco-costs per kilogram is presented.



Figure 2.9:  
Bamboo stem of  
the Moso  
species

Product	Eco-costs (€)/kg
Moso stem	0.842

Table 2.10:  
Eco-costs per  
kilogram of a  
5.33 m Moso  
stem

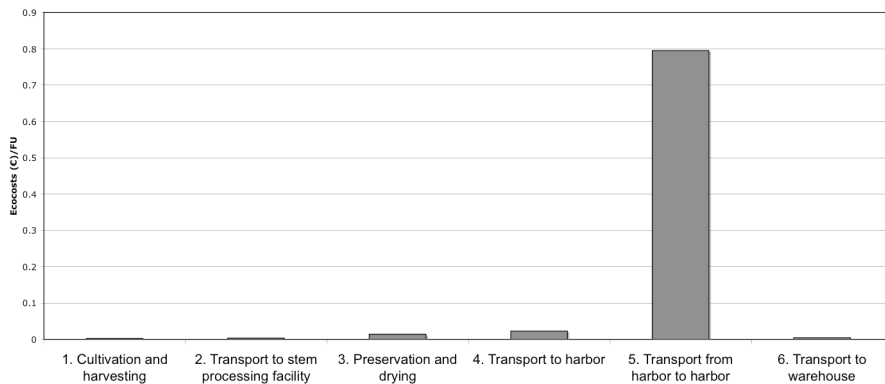


Figure 2.10:  
Environmental  
impact (eco-  
costs in €/kg) of  
the various  
process steps  
during the  
production and  
transport of a  
Moso stem

From Figure 2.10 two important conclusions can be drawn: 1) the bamboo stem goes through very few processing steps; besides the transport steps, after harvest and preservation bamboo can directly be used as input for applications, which shows the efficiency of the material (e.g. a tree is almost never used in its natural form in applications); and 2) almost all the environmental costs of the bamboo stem (94.5%; see Table A8 in appendix A) are caused by the sea transport of the stems from China to the Netherlands. Due to the large volume bamboo stems occupy in the container, the transport of the material to a very large extent determines the eco-burden of the

material, since for low weight sea transports the eco-costs are calculated based on the eco-costs per m<sup>3</sup>.km of the boat used (see for more details appendix A).

### Eco-costs per FU

As mentioned before, the eco-costs/kg do not say a lot unless a material is compared with other materials in a certain FU, in which both materials fulfill requirements for the same function. The unique properties of the stem are mainly its lightness and distinct aesthetic look. For the environmental assessment, a leg of the table developed during the project “Dutch Design meets Bamboo” by Ed van Engelen (not taking into account coating), was chosen as a FU.

Figure 2.11:  
Bamboo table  
designed by Ed  
van Engelen



In this particular application the size of the leg is determined by the aesthetics of the Table. Only for very thin legs, buckling and compression strength may become the critical property. Therefore, in this FU bamboo was compared with various softwood and hardwood species from plantations (Poplar, Pine, European Beech, European Oak and Teak) based on similar dimensions as the bamboo version: round legs of 0.8 m long with a diameter of 9 cm, resulting in a volume of the leg of 0.0051 m<sup>3</sup>. The weight of the bamboo stem was calculated with the average weight per m<sup>1</sup> of a 5.33 m long stem based on Table 3.3 in Section 3.2: 1.44 kg/m<sup>1</sup>, which equals 1.15 kilogram for a 0.8 m long segment. The results of the eco-costs per FU of bamboo compared to wood are represented in Figure 2.12 and Table 2.11, with in the final column of the table the ratio of eco-costs of the wood alternatives compared to bamboo. Note that in the calculation the life span, maintenance and end-of-life scenario is assumed not to be differentiating for the various alternatives in this application.

Material	Density (kg/m <sup>3</sup> )	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
Bamboo stem	700	0.842	1.15	0.97	100%
Bamboo stem (use in China)	700	0.046	1.15	0.05	5%
Scots Pine	500	0.05	2.55	0.13	13%
European Beech	670	0.04	3.42	0.14	14%
European Oak	700	0.04	3.57	0.14	14%
Poplar	440	0.03	2.24	0.07	7%
Teak (plantation)	650	0.21	3.32	0.7	72%
Teak (FSC)	650	1.70	3.32	5.64	581%

Table 2.11: Eco-costs per table leg for various wood- or bamboo based alternatives

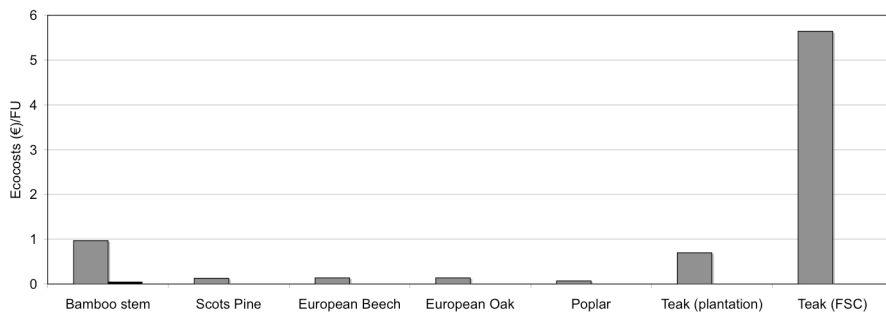


Figure 2.12: Eco-costs per table leg for various wood- or bamboo based alternatives

From Figure 2.12 and Table 2.11 several conclusions can be drawn. First of all can be seen that despite the low weight of the hollow bamboo stem (1.15 kg) compared to the solid legs made from wood (2.3 - 3.6 kg), due to the high eco-costs/kg caused by the sea transport, the bamboo stem has a higher environmental burden than almost all wood alternatives (except FSC tropical hardwood and tropical hardwood derived from natural forests). In case the bamboo stem is used locally (in this case in China), the eco-costs/FU will be drastically lower (see black column in Figure 2.12), and the bamboo stem performs even better than locally grown wood species (see Table 2.11).

In the Box 2.1, another comparison of the eco-costs was made between the bamboo stem and wood, this time for the use as a structural element in a walking bridge.

**Box 2.1: The Eco-costs of the Bamboo Stem and Wood in a Walking Bridge**

Figure 2.13:  
The bamboo  
walking bridge  
in the  
Amsterdam  
Woods



An earlier LCA calculation, based on the TWIN 2002 model (van der Lugt et al. 2003), has been recalculated based on the eco-costs 2007 method. The use of bamboo and wood in a transversal supporting beam (2.1 m) in a walking bridge in the Amsterdam Woods in the Netherlands was taken as FU (see Figure 2.13 for photos of the actual bridge executed in steel and bamboo). Bamboo was compared with two hardwood species (one European species and one tropical species) known for their suitability for outdoor use: Robinia and Azobé. The exact dimensions of the beam were determined to meet strength requirements ( $0.1 \times 0.2 \times 2.1\text{m}$  for Azobé, and  $0.12 \times 0.225 \times 2.1\text{m}$  for Robinia). In the original calculation, Guadua stems from Costa Rica were used for bamboo. Since the eco-costs calculation is executed for Moso, and Moso is a smaller and in general weaker species than Guadua, it is assumed that two Moso poles of 2.1 meters and a diameter of 9 cm are required with an average weight of 1.44 kg/m1, instead of one Guadua stem.

In this particular application, the durability outside differs for the various materials. So the life span needs to be taken into account for a comparison (Azobé 25 years, Robinia 15 years, Bamboo 10 years) (van der Lugt et al. 2003). As a reference, a steel beam (IPE 100, 22.3 kg, life span of 50 years) was also taken into account in this particular comparison. The results of the eco-costs per FU of bamboo compared to the alternatives are represented in Figure 2.14 and Table 2.12.

Material	Density (kg/m <sup>3</sup> )	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs (€) per FU per year	Eco-cost per FU per year (ratio)
Bamboo stem	700	0.842	6.0	5.05	0.51	100%
Bamboo stem (use in China)	700	0.046	6.0	0.276	0.03	5%
Robinia	740	0.05	42.2	2.11	0.14	27%
Azobé (plantation)	1060	0.09	44.5	8.19	0.33	62%
Azobé (from FSC certified plantation)	1060	0.86	44.5	38.28	1.53	303%
Steel	7850	0.487	22.3	10.86	0.22	43%

Table 2.12:  
Eco-costs per  
year for bamboo  
and wood used  
as a transversal  
beam in a  
walking bridge

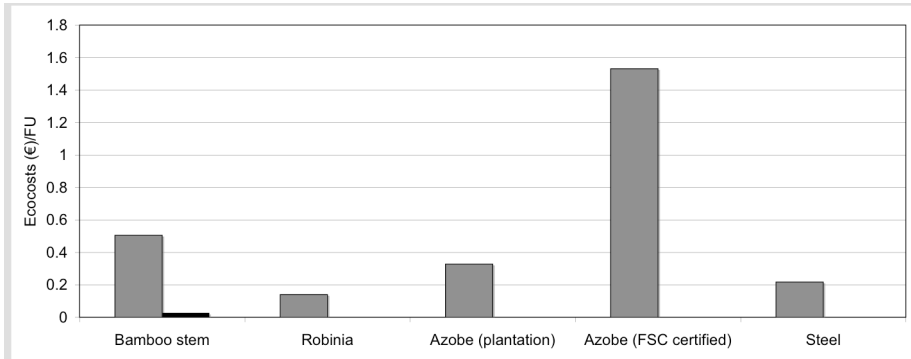


Figure 2.14: Eco-costs per year for bamboo and wood used as a transversal beam in a walking bridge

From the figure and table it can be concluded that, although the weight of the two bamboo stems combined in the function of transversal beam is the lowest of all alternatives, the eco-costs per FU per year are higher than all alternatives, except FSC certified Azobé.

In case bamboo is used locally (in China), the eco-costs of the bamboo stem are drastically lower (see black column in Figure 2.14).

It is interesting to see that steel (with high eco-costs/kg) is the most environmental alternative in this particular application due to the relative low weight of the I-profile compared to the massive wooden beams, and the long life span of steel (50 years).

## 2.5 Fibers

Bamboo fibers may be used as reinforcement in natural fiber reinforced composites suitable in various applications. Since production data of fibers was not available, they were not assessed for the eco-costs calculation. However, to provide some indication of the energy consumption during production of glass fibers (most often used in composites), carbon fibers and cellulose fibers (such as bamboo fibers), the reader is referred to Table 2.13.



Figure 2.15: Bamboo micro fibers

Table 2.13:  
Energy  
consumption  
during  
production of  
several fibers  
(Kavelin 2005)

Fiber	Energy consumption during production (MJ/kg)
Cellulose	4
Glass	30
Carbon	130

Note that in this Table the density of the materials and the FU is not yet taken into account; however, independent of these features, natural fibers seem to score quite well. Nevertheless, compared to other popular natural fibers (e.g. sisal, flax, hemp, jute, various wood species), bamboo needs to go through more processing steps before the fiber is distilled and/or has to be transported from further away. Therefore, it may be questionable if bamboo will be very competitive compared to other natural fibers in terms of eco-costs for use in Western Europe. This might be different for production of natural fiber based composites for local use, especially if researchers are able to efficiently distill the bamboo fiber from the stem without too many material losses, in order to utilize the large annual increase in biomass (see chapter 3).

## 2.6 Strand Woven Bamboo

Strand Woven Bamboo (SWB) is a relatively new industrial bamboo material that can be used indoors and outdoors, with a high hardness (2800 lbf) and density (1080 kg/m3) due to the compressed bamboo strips used in combination with a high resin content. The eco-costs calculation was based on the outdoor version (with a higher glue content and higher compression level) in a carbonized color. The eco-costs per kilogram calculation was based on the production and transport of one SWB plank of 1900 × 100 × 15 mm (0.00285 m3). For the complete calculation the reader is referred to appendix A. The eco-costs per kilogram for SWB are presented in Table 2.14. In Figure 2.17 the contribution of each process step to the eco-costs per kilogram is presented.

Figure 2.16:  
Samples of  
Strand Woven  
Bamboo (SWB)



Product	Eco-costs (€)/kg
SWB (carbonized)	0.524

Table 2.14:  
Eco-costs per  
kilogram of  
SWB

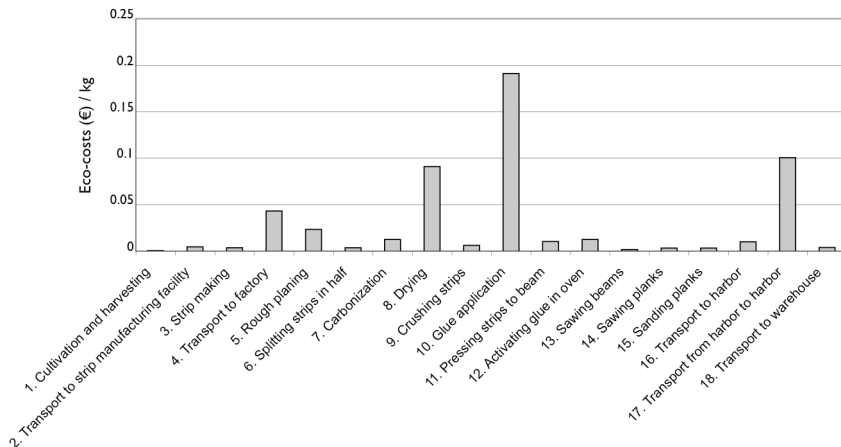


Figure 2.17:  
Environmental  
impact (eco-  
costs in €/kg) of  
the various  
process steps  
during the  
production and  
transport of a  
SWB plank

From Figure 2.17 it can be concluded that the Phenol Formaldehyde resin used (23% in the final product) has a large impact on the eco-costs/kg of SWB, accounting for 36.4% of the environmental burden. For more background information, the reader is referred to appendix A.

### Eco-costs per FU

One of the unique features of SWB is that, unlike other industrial bamboo materials, it seems suitable for use outdoors (van der Vegte and Zaal 2008); for more information see footnote 9 in Section 1.4. For this reason, the eco-costs of SWB were compared with wood alternatives in the function of terrace decking (FU) for outside use with dimensions of  $1900 \times 100 \times 15$  mm (0.00285 m<sup>3</sup>). In this application, besides aesthetics, the durability outside is the most important criterion for material selection, based on which alternatives for comparison with SWB were selected. Various tropical hardwood species (e.g. Teak, Azobé, Bangkirai) are well known for their durability outside. For the eco-costs calculation SWB was compared with Teak and Azobé, although Teak is the commonly used alternative for this application. Although Azobé is more often used in more demanding applications such as in bridges, this species was chosen for this calculation as a representative of a tropical hardwood species with relatively low eco-costs/kg (see Table 2.1). Since tropical hardwood is often used in outdoor applications, and it often is unclear if this wood is sourced from natural forests or plantations, the eco-costs for various scenarios (plantation, FSC certified, RIL harvested from natural forest) were calculated for Teak and Azobé.

Another method to increase the outdoor durability of timber is to modify softwood through impregnation, thermal modification or acetylation.

Impregnation is only functional if heavy metals (e.g. chrome, copper, arsenic) are used, which are poisonous for humans and will be released in the environment once the wood is disposed of. Impregnated wood has therefore received a lot of resistance in the West (“poison wood”) and is increasingly being replaced by supposedly more eco-friendly techniques to modify softwood. For this reason impregnated wood was not taken into account in this calculation.

Thermal modification is a more environmental friendly option. The durability of softwood is improved considerably through thermal treatment. There are several producers of thermally modified wood each using slightly different parameters. For this report, production data on Plato® Wood from European Spruce was used to calculate the eco-costs: 0,13 €/kg.

Acetylation is another method that is currently being commercialized, that can be used to modify the durability of softwood. In this chemical process wood reacts in kettles with acetic anhydride, through which free hydroxyls in the wood are formed into acetyl groups. According to Titan Wood (2008), the producer of acetylated wood, the process is 100% recyclable and non-toxic. An advantage of this method is that, as opposed to thermal modification, the mechanical properties of the treated wood slightly improve, which facilitates a larger range of applications for Accoya® (the trade name of acetylated wood) in constructive applications (e.g. bridges) compared to thermally modified wood. An LCI of the production data of acetylated wood can be found in Classen and Caduff (2007). Calculation shows that the acetylation process of Scots Pine results in eco-costs of 0.22 €/kg of Accoya.

Finally, a wood-plastic composite was also taken into account for this calculation; Tech-Wood® is a material which consists of 70% of Pine fibers and 30% of polypropylene (Tech-Wood 2008). As such the eco-costs/kg of the Pine fiber input for Tech-Wood accounts for  $0.05 \times 0.7 = 0.035$  €/kg. The eco-costs/kg of the Polypropylene part are  $0.3 \times 1.02$  (eco-costs/kg of polypropylene) = 0.306 €/kg. In total the eco-costs/kg for Tech-Wood are then 0.341 €/kg.

In Table 2.15 and Figure 2.19, the eco-costs per FU of the various alternatives are depicted. In the final column of the Table the ratio of the alternatives compared to SWB is provided. The eco-costs/FU are calculated based on the same dimensions of the decking plank as for SWB ( $1900 \times 100 \times 15$  mm = 0.00285 m<sup>3</sup>), except in the case of Tech-Wood. Since Tech-Wood profiles are made through a “push-trusion” process, around 40% less material is required (see Figure 2.18) than for a solid alternative. The density of Tech-Wood was based on the density and volume percentage of Pine (500 kg/m<sup>3</sup>) and Polypropylene (900 kg/m<sup>3</sup>). Because of thermal modification the weight of Plato® wood decreases by approximately 10% (Boonstra 2008), whereas the weight of Accoya® increases by approximately the same number (de Groot 2006), which was taken into account in Table 2.15.

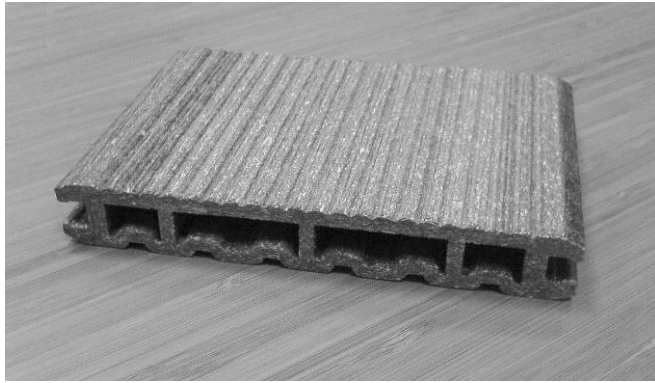


Figure 2.18:  
Sample of a  
Tech-Wood  
decking profile

Material	Density (kg/m <sup>3</sup> )	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
SWB	1080	0.52	3.08	1.61	100%
Teak (plantation)	650	0.21	1.85	0.39	24%
Teak (FSC certified)	650	1.70	1.85	3.15	195%
Teak (natural forest; RIL)	650	7.67	1.85	14.19	881%
Azobé (plantation)	1060	0.09	3.02	0.27	17%
Azobé (FSC certified)	1060	0.86	3.02	2.60	161%
Azobé (natural forest; RIL)	1060	3.96	3.02	11.96	742%
Plato wood	420	0.13	1.20	0.16	10%
Acetylated wood	550	0.22	1.56	0.34	21%
Tech-Wood	620	0.34	1.77	0.60	37%

Table 2.15:  
Eco-costs per  
year for SWB  
and alternatives  
for outside  
terrace decking

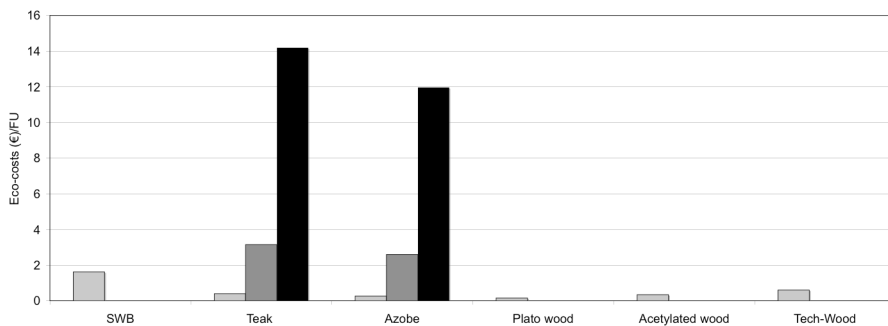


Figure 2.19:  
Eco-costs per  
year for SWB  
and alternatives  
for use in  
outside terrace  
decking

Note: for Teak and Azobé the light gray bar refers to plantation grown timber, the dark gray bar for FSC certified timber (unclear if from forest or plantation, see Section 2.2) and the black bar refers to timber derived from natural forests.

From Figure 5.19 it can be concluded that SWB has an environmental burden that is higher than for modified softwood (Plato wood and Accoya), Tech-Wood and suitable plantation grown tropical hardwood species (in this case Teak and Azobé). However, it has a lower environmental impact than FSC certified Teak and Azobé, and Teak and Azobé harvested from natural forests.

If SWB is used locally, the eco-costs will be considerably lower, since sea transport accounts for 19.2% of the total environmental burden, see Table A9 in appendix A. For inside applications it would be worthwhile to investigate to what extent the Phenol

formaldehyde resin in SWB could be replaced by completely biodegradable resins such as PLA. It can be concluded that in terms of eco-costs the use of SWB is recommended to help meet the growing demand for tropical hardwood sourced from natural forests (including FSC certified timber), although better performing alternatives from an environmental impact point of view (Tech-Wood and modified timber) are available and should receive priority.

## 2.7 Bamboo Mat Board

In Asia thin bamboo slivers and strips are commonly woven into large mats, which can serve as input for the production of various boards, including Bamboo Mat Board (BMB) which can be pressed into molds of various shapes (including corrugated boards). Since the production<sup>15</sup> and density (1030 kg/m<sup>3</sup>) of BMB (BMTPC 2002) and SWB are very similar and both materials use a large amount of resin, it was assumed for the calculation that the eco-costs/kg of both materials are similar.



Figure 2.20:  
Bamboo mats  
are available "on  
the roll"

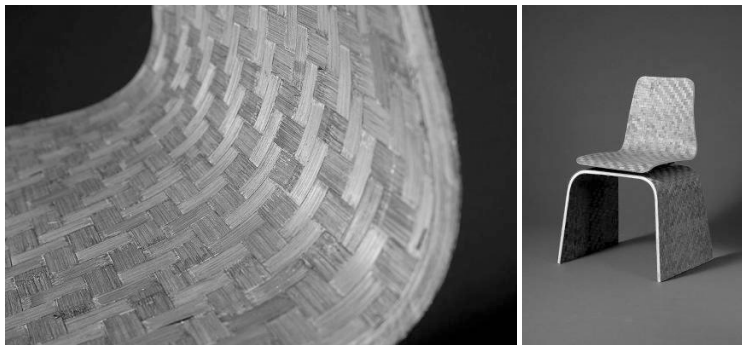


Figure 2.21:  
Chair made from  
bamboo mats,  
designed by  
Maarten Baptist

To compare BMB with alternatives on eco-costs, the molded seating as designed by Maarten Baptist during the project "Dutch Design meets Bamboo" (van der Lugt 2007) was chosen as FU. Since one of the unique properties of BMB is that it can be molded in three directions at the same time to form 3D structures, it was assumed that the

<sup>15</sup> According to Zhang Qisheng et al. (2003) the BMB production process is as follows: Strip making > weaving > glue application (usually phenol formaldehyde) > drying > hot pressing (in mold) > sawing.

seating was executed as a bowl (instead of the 2D bended seating in Figure 2.21). It is assumed that for the seating a piece of  $0.4 \times 0.4 \times 0.015$  m (0.0024 m<sup>3</sup>) BMB is required. Since 3D bending is not possible in wood, as a reference the calculation was also executed in ABS, a high end polymer suitable for use in 3D bowls. For the calculation it was assumed that the ABS alternative can be produced in a slimmer version than the bamboo alternative:  $0.4 \times 0.4 \times 0.003$  m (0.00048 m<sup>3</sup>). In Table 2.16 and Figure 2.22 the eco-costs/FU for BMB and the various alternatives are represented.

Material	Density (kg/m <sup>3</sup> )	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
BMB	1030	0.524	2.47	1.30	100%
ABS	1100	1.32	0.53	0.70	54%

Table 2.16: Eco-costs per year for BMB and alternatives used in a 3D molded seating

From Figure 2.22 it becomes clear that in this particular application BMB has an even higher environmental burden than ABS, which is one of the least environmentally friendly polymers. For local use the eco-costs might also be lower since sea transport will not play a role in that scenario. Furthermore, the environmental burden of BMB could be diminished by deploying a biodegradable resin such as PLA instead of Phenol formaldehyde.

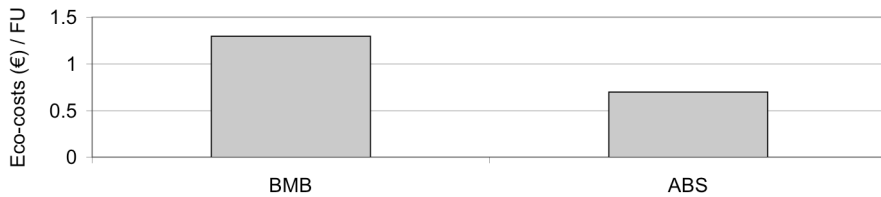


Figure 2.22: Eco-costs per year for BMB and alternatives for use in a 3D molded seating

Note that in the case of 2D bending, Beech, Plywood and Plybamboo are also eligible, which, due to the lower density and eco-costs per kilogram will have lower eco-costs when used in molded seatings (see Section 2.3).

In the Box 2.2, an example is provided about an eco-costs comparison of corrugated BMB roof sheets based on use in China.

Box 2.2: Eco-costs of BMB Corrugated Roof Sheets Based on Use in China

BMB is often also used in China and India as corrugated roof sheet. The production process is similar to the production process of regular BMB with the exception that the material is hot pressed in a mold (Zhang Qisheng et al. 2003). Furthermore, for the eco-costs per kilogram the eco-costs of transport (sea- and land transport to the Netherlands, see appendix A) should be deducted to acquire eco-costs for the local situation resulting in eco-costs/kg of € 0.419.

Corrugated BMB targets the low cost housing market in India and China and should therefore be compared with other low cost alternatives often used in these countries: corrugated steel sheet or corrugated PVC sheet. The alternatives were compared based on 1 m<sup>2</sup> of roof sheet (FU). Corrugated sheets in steel (thickness 0.6 mm) and PVC (thickness 2 mm) are thinner than BMB (thickness at 3.7 mm, see BMTPC 2002), thus a smaller amount of material is required for these alternatives. In Table 2.17 and Figure 2.24 the eco-costs per FU are represented. Note that in the calculation it is assumed that all alternatives have the same life span.

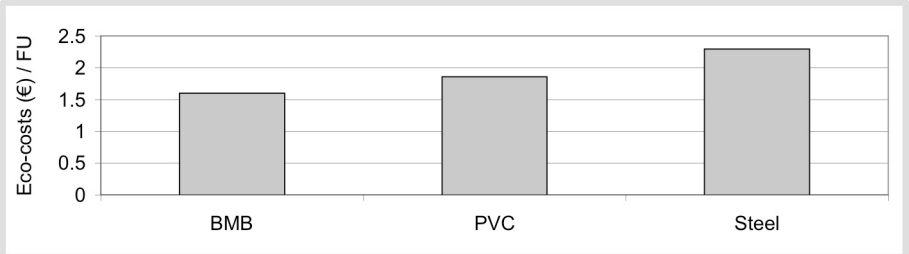
Figure 2.23:  
Corrugated  
board made  
from BMB



Table 2.17:  
Eco-costs per  
year for BMB  
and alternatives  
for use for in a  
corrugated roof  
sheet

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
BMB	1030	0.419	3.81	1.60	100%
PVC	1450	0.64	2.90	1.86	116%
Steel sheet	7850	0.487	4.71	2.29	144%

Figure 2.24:  
Eco-costs per  
year for BMB  
and alternatives  
for use for in a  
corrugated roof  
sheet



The Figure and Table show that if used locally, and if no plantation based wood alternatives are around for a particular application, industrial bamboo materials such as

BMB can compete on eco-costs with non-wood alternatives in applications such as corrugated roof sheets.