“The natural renewable building material-bamboo. A comparison between Germany and Indonesia.”

Felix Bernhard Haves [1]

Bachelor Degree of Architecture Study Program
Jade Hochschule Wilhelmshaven/Oldenburg/Elsfleth
Germany
fehav96@gmail.com

Abstract
It is foreseeable worldwide that in the future the topic of sustainability will have to be given greater importance. The same applies to the building industry. Bamboo is a natural, very fast growing raw material with very good properties which have great advantages in many areas. It doesn't grow all over the world, but it already has a lobby in non countries of origin. Now the question arises whether bamboo can become more important in the future as a building material in non-countries of origin due to sustainability problems. First of all the work deals with the climatic conditions that bamboo needs to grow and why it can't grow all over the world. Subsequently, bamboo as a raw material is discussed and it is worked out whether it has the right properties for an alternative and what could make it such a good alternative material. It is examined whether he can supplement or even replace other materials in countries of origin. Properties are confronted and compared.
My results show that bamboo, due to its properties and applications, has the potential to be a complement and/or an alternative to other building materials. However, there are some small factors that speak against it.
Further my results have shown that fundamentally much more thought has to be given to sustainable building. Bamboo can become a big factor of sustainability in the building industry in the future, but it is not enough to rest on it and the topic must be given a more important meaning.

***Index Terms*— Bamboo,Future,Non-Originating Countries,Sustainability.**

I. Introduction

When building with bamboo, care must be taken to ensure that not every type of bamboo can be used. The characteristics of the bamboo types are basically all very similar. Nevertheless, there are differences due to the dimensions and external conditions. Due to this assumption it is important to consider only bamboo species that are constructively relevant. It is known from previous research that bamboo is a natural and very fast growing raw material which has great advantages in terms of sustainability.

Sustainability will have to become much more important in the future as not all raw materials on earth are infinite. There is a lot of research going on to develop new sustainable materials. The unconscious ignorance for naturally renewable materials with high sustainability like bamboo, which has been around for thousands of years, is obvious. Nevertheless, there are researches that deal with bamboo as a building material and promote this topic, because they consider a future to be very well possible based on already acquired knowledge. First of all I will deal

with the topic of climatic conditions, because at the beginning it has to be clarified why there are countries without bamboo deposits at all. Then I go into the general aspects of bamboo in order to know which types of bamboo are suitable as building material. Afterwards the relevant characteristics are examined and classified. In order to illustrate these properties, successfully completed construction projects with bamboo will be presented below. The fact that there is research which also deals with the topic I show by a case study. This case study deals very well with bamboo as a supplementing and/or replacing building material. Subsequently, I will deal with comparable materials, which are spread in Germany and which can be considered for a supplement and replacement.

I expect to be able to answer my question by dealing with the relevant topics and working out the subsequent comparisons, examples and juxtapositions. Putting the individual aspects into a permanent context will help me to get an acceptable answer.

II. Result and Analisys

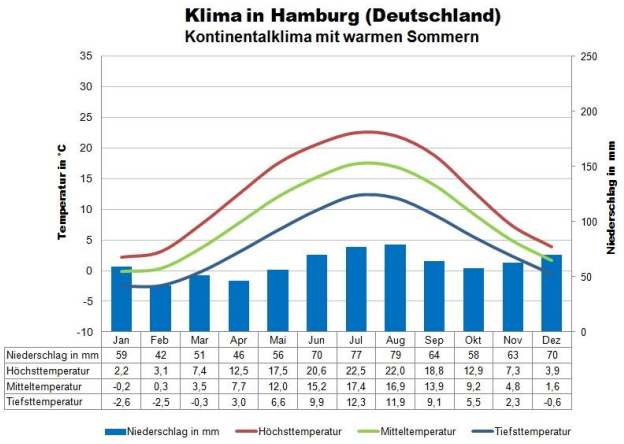
A. Climate Conditions in Germany

The macroclimate of Germany is the typical, temperate climate of Central Europe. However, the east-west extension and the considerable south-north extension as well as the numerous low mountain ranges lead to considerable regional climate differences. Due to my place of study and residence I would like to refer to Northern Germany.

In the north of Germany, the North Sea and Baltic Sea have a very strong maritime influence on the climate. But there are also differences between the North Sea and the Baltic Sea too. Rainy summers and mild winters with strong storms characterize the North Sea coast and its backlands. At the Baltic Sea the summers are drier and hotter.

Another important climate factor in Germany is the Gulf Stream. It is responsible for the fact that the temperatures are relatively high in spite of the northern latitude.

In Germany, the average air temperature is 8 degrees per year. The lowest average temperature is reached with -0.5°C in January, the highest with 17-18°C in July. Northern Germany has only 500-700 mm precipitation . The winter months in Germany are always very cold and foggy. This period takes place from December to March. In large parts of Germany, temperatures below freezing regularly occur. The summer months of June to August can also be very hot in Germany. In many regions day temperatures above 30°C are not rare, even if not permanent. Germany has an average of 108 rainy days per year. The average number of sunny hours per day is 4,6.



	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Niederschlag in mm	59	42	51	46	56	70	77	79	64	58	63	70
Höchsttemperatur	2,2	3,1	7,4	12,5	17,5	20,6	22,5	22,0	18,8	12,9	7,3	3,9
Mitteltemperatur	-0,2	0,3	3,5	7,7	12,0	15,2	17,4	16,9	13,9	9,2	4,8	1,6
Tiefsttemperatur	-2,6	-2,5	-0,3	3,0	6,6	9,9	12,3	11,9	9,1	5,5	2,3	-0,6

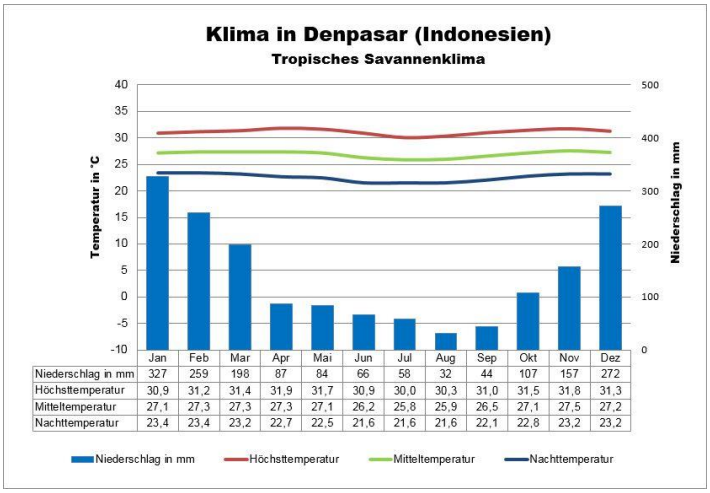
Fig. 1. 1 Klima in Hamburg (Deutschland) Kontinentalklima mit warmen Sommern Temperature (°C) left, precipitation (mm) right and blue bar, maximum temperature (°C) red line, medium temperature (°C) green line, lowest Temperature (°C) blue line (https://www.beste-reisezeit.org/pages/europa/deutschland.php#Deutschland_Klimazone)

B. A. Climate Conditions in Indonesia

The north (e.g. Sulawesi, Sumatra, Java, Bali, Lombok, Moluccas, Borneo) has a tropical humid climate. Precipitation falls in all seasons; only in the summer months it becomes a little less humid. The yearly amount of precipitation is around 3,000 to 4,000 mm (Blue bars in diagram). In the mountains it can be partly over 6,000 mm. On the Moluccas it is different, there the maximum rainfall is reached between April and August.

On the southern islands (Central and East Java, small Sunda Islands and Aru Islands) there is an alternately humid, tropical monsoon climate. Depending on the prevailing wind direction - northeast monsoon (November to March) or southwest monsoon (May to September) - there is a humid and humid rainy season (October to April), a dry post-monsoon season (May/June) and a hot dry season in the months July to September. The annual amount of precipitation in the months December to March is about 2,000 to 3,000 mm.

To the east, the rainy days and the amount of precipitation decrease. Dry air masses from Australia ensure an extensive dry season in summer. The daytime temperatures also do not show any great differences. During the day the temperatures are at least over 30 degrees (Red line in diagram). At night they drop to about 21-24 degrees (Blue line in diagram). The high air humidity of 90-95 % provides nearly everywhere and almost always a large sultriness. Indonesia has an average of 144 rainy days per year. The average number of sunny hours per day is 5.4.



	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Niederschlag in mm	327	259	198	87	84	66	58	32	44	107	157	272
Höchsttemperatur	30,9	31,2	31,4	31,9	31,7	30,9	30,0	30,3	31,0	31,5	31,8	31,3
Mitteltemperatur	27,1	27,3	27,3	27,3	27,1	26,2	25,8	25,9	26,5	27,1	27,5	27,2
Nachttemperatur	23,4	23,4	23,2	22,7	22,5	21,6	21,6	21,6	22,1	22,8	23,2	23,2

Fig. 2. Klima in Denpasar (Indonesien) Tropisches Savannenklima Temperature (°C) left, precipitation (mm) right and blue bar, maximum temperature (°C) red line, medium temperature (°C) green line, lowest Temperature (°C) blue line (https://www.beste-reisezeit.org/pages/asien/indonesien.php)

Many types of bamboo, including those that are constructively relevant, grow in Indonesia. Large parts of Indonesia are located at the height where bamboo shows optimal growth (500-1500 meters). Furthermore, the amount of precipitation in Indonesia is close to the amount that makes bamboo grow best (1200-2500mm per year). With optimal temperatures for proper growth, averaging between 18 and 24 degrees Celsius, bamboo is geographically perfect in Indonesia. The humidity levels which allow bamboo to grow fastest (80-90%) are almost exactly the same as in Indonesia.

C. Bamboo

Bamboo is a subfamily in the family of sweet grasses. The word bamboo comes from the late 16 century from the Dutch "bamboes". This in turn comes from the Malay word mambu.

About 1000 to 1500 species of bamboo are native to all continents except Europe and Antarctica. Their range extends from 46° north to 47° south. The different species grow from sea level to an altitude of about 4000 meters. The species are divided into two groups according to their distribution area: bamboo species in the temperate zone and tropical and subtropical species.

In bamboo, as in other grasses, the internode areas of the stem are usually hollow and the vascular bundles are not arranged in a cylindrical cross section, but distributed over the entire stem. The dicotyledonous woody xylem is also missing. The absence of secondary growth wood means that the stems of monocotyls, including palms and large bamboos, are columnar rather than tapering.

Bamboo is one of the fastest growing plants in the world due to its unique rhizome dependent system. Giant bamboos such as Dendrocalamus giganteus are the largest members of the grass family. Some bamboo species can grow within one day, 91cm. This corresponds to one millimetre of growth every 90 seconds. Bamboos are of remarkable cultural and economic importance in East Asia, Southeast Asia and South Asia and are used as a source of food, building materials and as a versatile raw product. It has a higher specific compressive strength than wood, concrete or brick. The specific tensile strength is close to that of steel.

D. Technically Relevant Properties for the Building Industry

First of all it has to be said that bamboo is a natural material which therefore cannot be standardized. There are big differences between species and individuals. The characteristics of a bamboo depend among other things on its species, the individual genetic characteristics and its current environmental condition. Especially the humidity and the temperature are a factor.

Bamboo is basically a hard grass and not a wood-based material. In its stems the tension is much more evenly distributed than in wood. This alone suggests that bamboo can keep up with conventional wood. However, the bamboo stems often have very thin walls and are hollow. Because of this the connection of bamboo stems is more difficult than that of solid wood. The chemical composition of bamboo is decisive for its constructionally interesting properties. The essential components of bamboo are cellulose and lignin (approx. 25%). The lignin content determines the compressive strength, the cellulose content the buckling and tensile strength.

Bamboo has many advantages. Because of its hollow shape it is very strong and stiff. It has the ideal properties for earthquake and typhoon areas, as it is not brittle and does not collapse when the earth quakes.

Thus the danger of collapsing buildings in crisis areas decreases when building with bamboo. The surface is polished, hard and clean and therefore does not have to be treated for every purpose. It is a building material which can be used by everyone at a very reasonable price as it can grow in a private garden. Due to the rapid growth of bamboo forests, a faster return of the inverted capital is ensured. Wood forests in comparison can be harvested with good forest management often only after several generations.

Bamboo also has disadvantages compared to other building materials. It is highly flammable and can only be used in the affected areas after appropriate treatment. The bamboo sticks are never completely straight and can therefore not be standardised. Bamboo has a short natural resistance and is therefore very susceptible to pests and weathering. Preventive measures such as appropriate treatment are more difficult than with wood.

In addition, it must not come into contact with damp soil, otherwise it swells up and loses its properties. For this reason, supporting bamboo trunks must have a foundation and bamboo walls must be at a distance from the ground.

The moisture content in the bamboo stems is decisive for strength. The more humid the bamboo, the less hard it is.

The effort required for processing such as cutting, sawing, drilling and splitting is reduced. Its main attractiveness as a building material comes from its strength properties.

Bamboo fibres are twice to three times as strong as steel when pulled. Scientists want to use this enormous tensile strength to produce a sustainable alternative to conventional reinforcing iron from bamboo. They call it "green steel". The outer skin of bamboo is more tensile than the inner skin. Accordingly, slim tubes are superior to thicker tubes in relation to the cross-sectional area. Based on this knowledge, it can also be said that thin tubes have a higher bending strength than thick tubes. The compressive strength of bamboo (which is suitable for constructions) is superior to almost all types of wood after tests.

Bamboo canes are particularly resistant to bending. A big advantage is also that the freshly cut bamboo canes are first subjected to a pre-bending in the case of unavoidable deflection in order to be balanced again at a later load.
In his dissertation Julius Joseph Jansen shows the qualities of bamboo under pressure perpendicular to the fibre using a very vivid example.

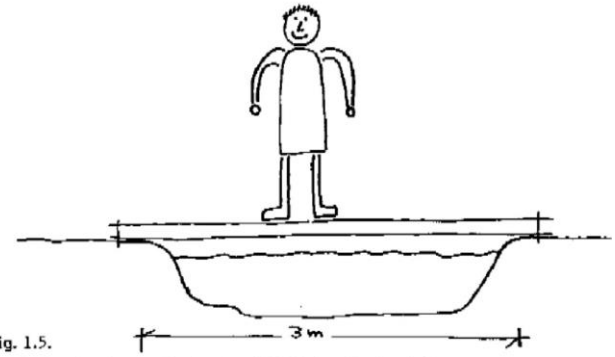


Fig. 3. The same concerning bending, for which case a simple bridge is calculated. The same scenario was executed with different materials. These were checked for deflection in terms of weight and dimensions. (Julius Joseph Antonius Janssen, Bamboo in building Structures, Page 15)

material	stress N/mm²	cross-section mm	deflection mm	mass of bridge kg
Concrete (reinforced)	10	40x100	9	32
Steel	160	30x30	31	13
Wood	10	35x100	15	6
Bamboo	10	100/80	7,5	5

Fig. 4 Efficiency of materials in the bridge of Fig.3
Bamboo and wood are also efficient when bending, only 5kg or 6kg are needed.

E. Applicaion Examples

The examples shown in this chapter refer to the aforementioned applications of bamboo. All examples are taken from the previously announced literature "Bamboo" by Àlex Sánchez Vidiella.

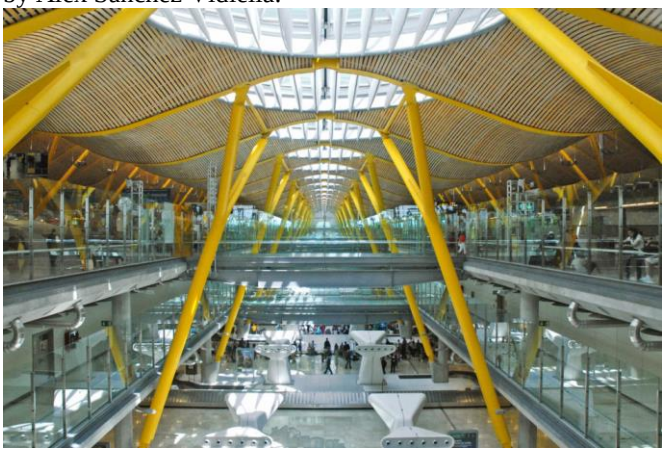


Fig. 5 Madrid-Barajas Airport-Estudio Lamela Arquitectos,Richard Rogers Partnership-Barajas,Spain,2004 (https://revistasumma.com)

The roof of the terminal was clad with 212,000m². It is the largest construction project in the world using bamboo. The material was chosen because it is a natural and sustainable alternative to wood. The special feature of this project is the treatment of the wood so that it is fireproof. The panels create a warm atmosphere inside. Due to a special technique, the bamboo panels were made flexible and could thus be bent into the undulated metal structure. The undulating shape of the roof is intended to resemble the silhouette of a flying bird.

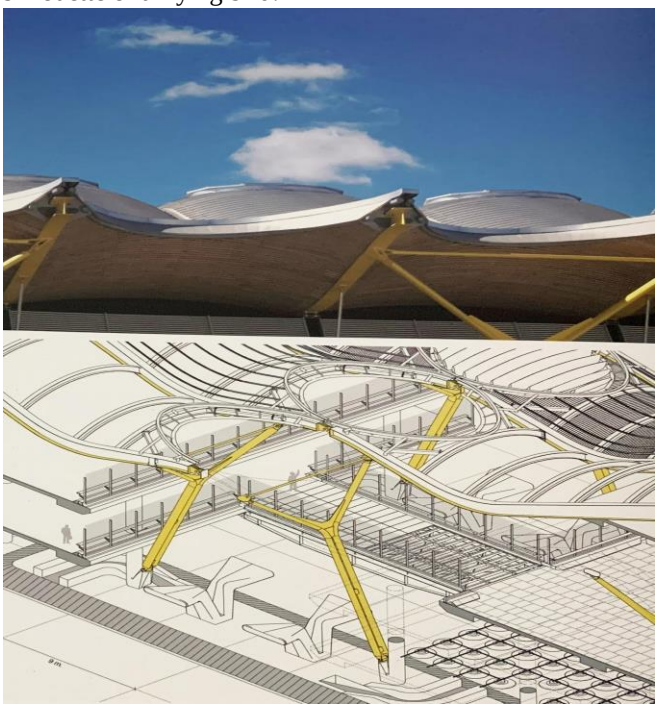


Fig. 6 Axonometry-Madrid-Barajas Airport-Estudio Lamela Arquitectos,Richard Rogers Partnership-Barajas,Spain,2004 Literature:"Bamboo" by Àlex Sánchez Vidiella, 2011 Page 106 This axonometry shows the construction of the roof. It illustrates the undulating form.

Fig. 7 Bamboo Forest House-ROEWU architecture-Luo-ong,Taiwan,2008
Literature:"Bamboo" by Àlex Sánchez Vidiella, 2011 Page 32
In this building the bamboo canes create the facade of the building.

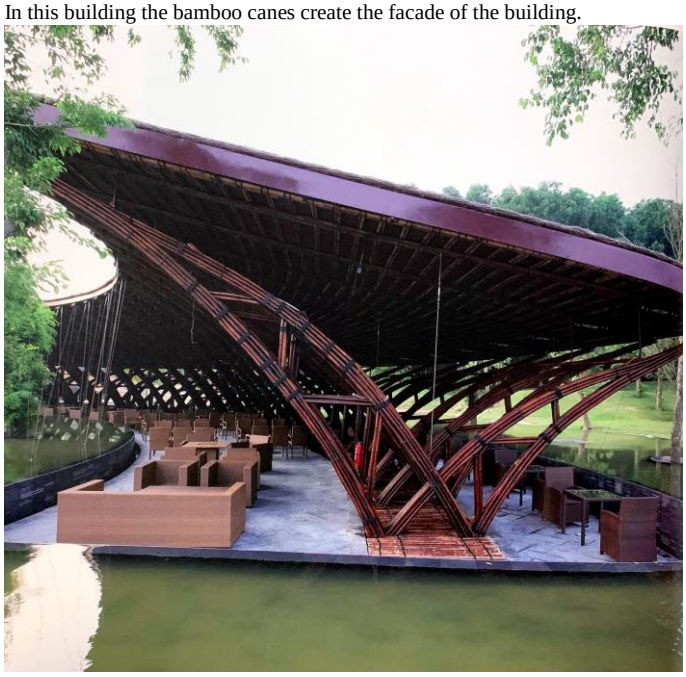


Fig. 8 Bamboo Wing-Vo Trong Nghia-Phúc Yên,Vietnam,2009 Literature:"Bamboo" by Àlex Sánchez Vidiella, 2011 Page 288 The construction after the completion of the building.

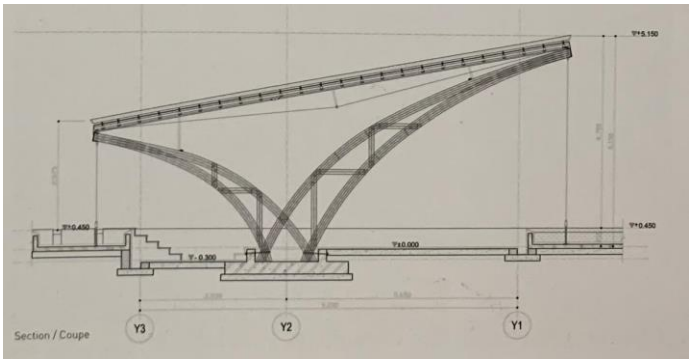


Fig. 9 Section, Bamboo Wing-Vo Trong Nghia-PhúcYên,Vietnam,2009
Vidiella, 2011 Page 292
This is a sectional drawing which illustrates the dimensions and construction of the building.

In this project, great importance was attached to the promotion of bamboo as a sustainable and efficient building material. It should prove as bamboo as structural material. Therefore no other artificial material was used. The shape of the pavilion was inspired by a flying bird. The pavilion offers the perfect space for events such as weddings, music concerts and ceremonies due to its 12m air space, which has no pillars.

Fig. 10 wNw Bar-Vo Trong Nghia-Thu Dau Mot, Vietnam,2008
The exterior view of the building, which is situated at a lake.
https://aasarchitecture.com/2012/
08/wnw-bar-by-vo-trong-nghia.html

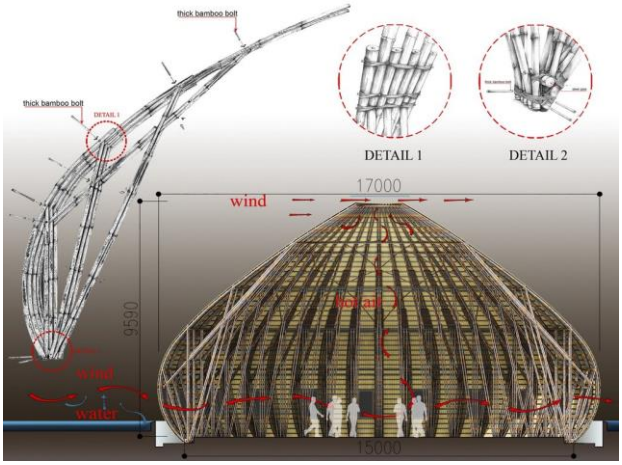


Fig. 11 wNw Bar-Vo Trong Nghia-Thu Dau Mot, Vietnam,2008
The construction of the building with corresponding details of the bamboo columns. https://aasarchitecture.com/2012/
08/wnw-bar-by-vo-trong-nghia.html/

The building, which is situated on an artificial lake, hosts events such as concerts, performances and ceremonies. The dome is 10m high and 15m in diameter. To achieve this, a structural system of 48 prefabricated bamboo arches was developed and built. Such a unit is made of different bamboo elements connected to each other. A special feature of the building is the natural ventilation in the interior in addition to the enormous structural system. This is done by the natural wind in combination with the cold sea water. The wind pushes the cold sea air through the building, at the same time the warm air inside rises and escapes through a 1.5 m wide hole in the roof [10].

III. CASE STUDIE

A. Research Centre of Eth Zürich in Singapore

Since 2010, ETH Zurich has had a research centre in Singapore that focuses on how urban centres can live as environmentally friendly as possible in the future. The team of around 100 scientists consists of architects, civil engineers, chemists and wood technicians.

Bamboo has the potential to become an export hit.

The situation in developing countries could be decisively improved by locally produced, low-cost building materials. The bamboo project was also nominated for an architecture prize by an international jury. The jury was very interested in the sustainability goals in connection with the properties of bamboo. The project leaders believe that the "South" will export the innovative, green material in the future to countries that are not countries of origin. But there are still some difficulties to overcome.

The laboratory splits the bamboo canes lengthwise until the individual plant fibres are visible.

The problem is that the fibres absorb and release water, which in the past led to shrinkage cracks. In combination with materials such as concrete, the fibres led to shrinkage cracks which became even larger when they dried out. The natural fibres of bamboo were also susceptible to bacterial, insect and fungal attack. In experiments large damages developed.

Based on this, the researchers at ETH Zurich developed a process in which the dissolved bamboo fibres are wetted with adhesive. They are then heated and pressed into a freely chosen shape. The fibres are sealed by the adhesive and are then water-repellent and resistant to insects or fungal infestation. The use of the bamboo composite material is currently being tested in carrier systems and pillars such as those used in steel or timber constructions. To ensure that as much renewable resources as possible are used, an epoxy resin based on vegetable oil is used instead of crude oil

B. Compare With Most Similar German Construction Materials. Can Bamboo Supplement or Even Replace These Building Materials?

STEEL

Steel is a material consisting mainly of iron. There are different steels with different properties which differ due to their composition and processing. For example structural steel, prestressing steel or reinforcing steel. The construction industry is responsible for 35 % of the steel used in Germany. Steel is very resistant, hard and tough. Despite these properties, it can be treated with many processing methods. Due to its strength, steel is excellently suited for load-bearing structures. As already mentioned, bamboo, which can be used as a construction material, has comparable strengths and is therefore a serious substitute for steel. Further reasons why bamboo could replace steel in some construction projects are the issues of sustainability and ecological aspects.

Bamboo is a natural material that is unlimited and easy to grow. It grows extremely fast and is ready to be harvested after a few years.

CO_2 is known to be a greenhouse gas that is particularly harmful to the climate.

The German steel industry alone emits about 67 million tons of CO_2per year.

Bamboo is able to store more CO_2 than any other plant and is therefore an important and fast CO_2 fixator. In special silicate cells the CO_2 is even permanently trapped and therefore completely isolated from the atmosphere. Most bamboo products are CO_2 neutral compared to steel.

Bamboo is easier to process than steel because of its properties. The fire resistance of steel can also be achieved with bamboo by a simple treatment. Bridges over wide rivers or multi-storey buildings which are still very often built with steel today can also be constructed with bamboo in the future. With regard to the ongoing research and statements of the experts, this is no longer a distant future. Steel has a high durability due to its high strength and its additional treatment such as an alloy. According to experts, the durability of bamboo corresponds to the expected lifetime of building materials of 50 to 80 years.

WOOD

The bamboo plant grows in contrast to the tree up to a height of 4000m. In contrast to the tree, several trunks grow out of one root. This increases the yield of material at a growth height of up to 40m because the trunks of a bamboo plant can also be harvested independently of each other.

Wood, on the other hand, is obtained from a variety of trees (among others oak, beech, spruce, fir).

In contrast to bamboo, many trees are not only used for wood production but also for energy production. The wood is used as wood chips or wood pellets to generate heat and electricity.

While most woods grow for more than 50 years, bamboo only needs 3-5 years to harvest. 70-80 years pass until tropical woods are ready for harvesting. The numbers of the increasing biomass speak clearly for the bamboo. On

average, this increases by 10-30% per year, whereas wood only reaches a maximum of 5%.

Bamboo stores basically more harmful CO_2 and produces in addition up to 45% more oxygen than a normal grown tree. Thus bamboo is neutral despite the long transport CO_2.

A further advantage of bamboo is that the entire plant is not felled during harvest, but only the useful trunks. This also prevents erosion, as the plant always remains and only new shoots need to grow. Tropical wood which is completely cut down on a large scale in rainforests does not grow new on its own and the soil becomes more vulnerable to erosion.

Bamboo has to look after the production of wooden materials such as wooden slats. It must first be split, dried and then glued. Whereas the wood only has to be cut to size.

Bamboo is an ideal substitute for brighter woods such as birch or coniferous due to its higher stability.

Due to its high durability and low weight, it is often more attractive than wood. Due to its homogeneous structure, bamboo hardly warps or works. The possibility to give bamboo a personal taste by oiling and varnishing is also possible without problems.

IV. Conclusion

In the beginning is to say that basically not every type of bamboo is usable as a building material. It has to be said that the properties are not fundamentally different but that the strengths of some types of bamboo are higher.

From a climatic point of view it is basically not possible to grow bamboo in countries of non origin under natural conditions. However, there are now research results that show that it is possible to grow bamboo under artificially created conditions. Whether this will become ecologically attractive in the future is to be observed further.

On the basis of such results one notices, however, that bamboo meets acceptance in various research and is investigated. If it is not possible or justifiable in the future to let bamboo grow artificially, developing countries with natural bamboo deposits could boost their economies through large exports. This could help some developing countries out of their difficult economic situation. Researchers in this field believe that there are still some unknown difficulties.

In the ETH Zurich case study discussed here, we are talking about a bamboo composite material that is currently being tested. It will be exciting to see whether the tests will be as promising as announced and whether the developed material will meet with the approval of the construction industry and therefore has a future.

In my opinion, too little research is carried out on the basis of existing materials. Most experts in the field pay too little or no attention to these materials. There is usually the opinion not to invest precious time and money in well-known materials but to devote oneself to new ones.

From an ecological point of view bamboo is also a good alternative. It can also be used for a wide range of applications.

Bamboo can also be a good choice for climate protection because of its neutral properties, as it absorbs CO2 and does not release it back into the atmosphere.

Bamboo is a possible building material due to its strength. This is proven by tests and does not meet with opposition. This thesis is reinforced by already built projects with bamboo which are often awarded international prizes.

Related to the materials used in Germany which I have brought into context, it can be said that bamboo has an enormous potential to complement these materials and in some cases even to replace them. However, it is clear that bamboo will not replace any of the materials completely and forever, as the other materials also have properties that bamboo cannot provide. It also comes up against its limits, at the latest then other materials such as steel can not be neglected.

Now that I have dealt with the topic in detail, I can say that bamboo can become a great alternative in many aspects in the future in countries of non-origin. Even if it cannot replace other materials fundamentally, it can supplement them with bamboo materials developed in the future. In addition to the structural aspects, Bamboo has outstanding properties with regard to the ecological aspects and the topic of sustainability and can therefore become a very big factor in the global future.

References

[1] Pile, John, “Color in Interior Design”, USA : The McGraw- Hill Companies, 1997.

[2] Kurniawati, Novriyana & Nanik, Rachamniyah, “Desain interior SPA Bernuansa Modern Natural Pada Pusat Kecantikan di Surabaya”, Jurnal Teknik Pomits, 2012.