Green Steel - constructing alternatives out of bamboo

Prof. Dirk E. Hebel with Felix Heisel, Alireza Javadian, Mateusz Wielopolski, Karsten Schlesier, and Dragan Griebel
E-mail: hebel@arch.ethz.ch

Steel-reinforced concrete is the most common building material in the world, and developing countries use close to 90 percent of the cement and 80 percent of the steel consumed by the global construction sector. However, very few developing countries have the ability or resources to produce their own steel or cement, forcing them into an exploitative import-relationship with the developed world. Out of 54 African nations, for instance, only two are producing steel. The other 52 countries all compete in the global marketplace for this ever-more-expensive, seemingly irreplaceable material.

But steel is not irreplaceable. There's a material alternative that grows in the tropical zone of our planet, an area that coincides closely with the developing world: bamboo. Bamboo belongs to the botanical family of grasses and is extremely resistant to tensile stress and is therefore one of nature's most versatile products. In its ability to withstand tensile forces, bamboo is superior to timber and even to reinforcement steel.

Bamboo is also a highly renewable and eco-friendly material. It grows much faster than wood, is usually available in great quantities, and is easy to obtain. It is also known for its unrivalled capacity to capture carbon and could therefore play an important role in reducing carbon emissions worldwide – another advantage for developing nations in light of the trade in carbon emission certificates. Simply from an economic perspective, most developing nations should be interested in the material. It could strengthen local value chains, bring jobs and trade to those countries, and lower their dependency on international markets.

The great social, economic, and material benefits of bamboo and its widespread availability are not reflected in the demand for the material, however. Despite its strengths, bamboo has a number of weaknesses as a construction material. Water absorption, swelling and shrinking behavior, limited durability, and vulnerability to fungal attacks have limited most applications of bamboo so far. Today, bamboo is generally limited to traditional applications of the culm as a structural component in vernacular architecture; early attempts to use it as an untreated, non-composite reinforcement material in concrete were not successful. The technology to improve the material hasn't been developed yet, probably because most countries with major bamboo resources are in the world's developing regions and have little, if any, industrial capacity.

At ETH Singapore's Future Cities Laboratory (FCL), a team of young researchers is working to tap bamboo's potential by exploring new types of composite bamboo material. The material's tensile

strength aroused our interest as architects and engineers and inspired us to investigate the possibility of extracting the fiber from the natural bamboo, transforming it into a manageable industrial product, and introducing it as a viable building material, an alternative to steel and timber. Bamboo composite material can be produced in any of the familiar shapes and forms in which steel and timber are produced. Like them, the material can be used to build wall structures for houses or any other buildings. More interestingly, it can be used for specific applications that best take advantage of the material's tensile strength, such as reinforcement systems in concrete or beams for ceilings and roof structures.

Worldwide, there are approximately 1,400 known species of bamboo. They demonstrate a very wide range of material properties. Some of the largest species can grow over 30 meters tall with a culm diameter of up to 15 centimeters; others only reach a height of around one meter with very thin culms. Accordingly, the tensile strength of the fibers also varies quite a bit. Some have almost no tensile capacity at all, while others are similar in strength to glass fibers. All of this depends on the region and climate in which the bamboo grows and the evolutionary adaptations it underwent. Using new technologies, we're studying which bamboo species are most suited to use it as a high tensile composite material for the construction industry and how we can overcome some of bamboo's material limitations by combining it with adhesive matter. The technology and machinery for the production of such composite materials could be described as "low-tech" while the research focusing on the development of suitable adhesive and cohesive agents is focusing more and more on a "high-tech" micro- and nano-level.

International researchers have spent decades searching for ways to capitalize on bamboo's strengths and transform bamboo from a locally-used, organic material into an industrialized product. Interest in bamboo as an industrialized construction material can be traced back to the year 1914, when PhD student H. K. Chow of MIT tested small-diameter bamboo and bamboo splints as reinforcement materials for concrete. Later, many other research institutions, including the Technische Hochschule Stuttgart under Kramadiswar Datta and Otto Graf in 1935, tried to find appropriate applications for the outstanding mechanical and technical properties of bamboo, with little success.

In 1950, Howard Emmitt Glenn of the Clemson Agricultural College of South Carolina (now Clemson University) started to conduct more extensive research on reinforcing concrete with natural bamboo. He and his team actually tested bamboo-reinforced concrete applications by building several full-scale buildings, utilizing his experience from work he had conducted in 1944 on bamboo-reinforced concrete beams. Using only small-diameter culms and bamboo splints, he demonstrated that the application was feasible in principle; however, bamboo's elastic modulus, susceptibility to insect and fungus attacks, coefficient of thermal expansion, and tendency to shrink and swell all represented major drawbacks and failures. Due to de-bonding between the bamboo and concrete, structures that were built using natural bamboo as reinforcement collapsed days after construction. After these disappointing results, research almost came to a full stop.

In 1995, Khosrow Ghavami of the Pontificia Universidade Catolica in Rio de Janeiro started a new series of mechanical tests on seven different types of bamboo. He hoped to determine which was the most appropriate species for use as reinforcement in newly developed lightweight concrete beams. Concrete beams reinforced with natural bamboo splints demonstrated a remarkable superiority, in

terms of the ultimate applied load they could support, to beams reinforced with steel bars. This proved that, in laboratory conditions, it is possible to utilize the load-bearing capacity of bamboo in a concrete application. However, the long-term behavior of bamboo in concrete structures remained problematic.

The different thermal expansion coefficients of bamboo and concrete will inevitably result in the de-bonding of the two materials. Since bamboo is a natural material, it will absorb water when exposed to a concrete matrix, leading to a progressive de-bonding of the bamboo from the concrete due to excessive swelling and shrinking. This expansion of the volume will also create tiny cracks in the concrete, weakening the structure more and more over time and allowing biological attacks on the bamboo.

At the FCL, extensive research is underway to investigate in a renewable reinforcement material made out of bamboo and adequate adhesive agents. Our aim is to form a water-resistant, non-swelling, durable composite material that takes advantage of bamboo's incredible physical properties while mitigating its undesirable qualities. The final material reaches a density roughly three times higher than that of natural bamboo. The current research focuses on three areas: treatment of the bamboo, adhesives, and a standardized production process. As bamboo is still, in most countries, not considered to be an industrial, processed resource, standardization criteria and systems need to be developed to conduct the research on the strictest possible scientific terms.

If successful, the research could provide a starting point for the introduction of new and adapted technologies that take a widespread natural resource as their basic premise. Today, bamboo costs less than a quarter as much, by weight, as steel reinforcement. And because steel is 15 times denser than natural bamboo, the figures by volume are even more extreme. In Southeast Asia alone, there is enough bamboo already in cultivation to provide 25 times as much bamboo composite as there is, today, demand for construction steel in the same area. Bamboo's natural habitat is largely congruent with developing territories, which, with this new technology, could potentially develop substantial value chains. Farmers, collection centers, distributors, and finally production facilities could form a strong economic power – so long as the bamboo is not simply exported as a raw material. Developing countries must develop and sustain knowledge and industrial know-how in order to strengthen their economic capacities. The production of a high-strength building material could establish strong new rural-urban linkages and create an alternative source of revenue for farmers. Expanding bamboo cultivation would help farmers in other ways, too; due to its fast growth, bamboo can secure open soil and protect it against erosion. Being a grass, bamboo also keeps the water table high and therefore improves the productivity of adjacent fields planted with food crops. Bamboo could play an important role not only as a traditional resource for vernacular construction but also as the major component of an industrialized product, enabling the creation of a "smoke-free" industry in developing nations.

Today, most developing territories – with an ever-growing population, rising urbanization, and, consequently, an ever-increasing need for housing structures – are found in a belt around the equator. East Africa, for example, is urbanizing at a rate of 5 percent per year.[1] Singapore, where we are conducting our research, neighbors the "magic triangle," the fastest developing territories in the world today: India, China, and Indonesia. Within a radius of 4000 kilometers – only 9.8 percent of

[1] World Urbanization Prospects, the 2011 Revision, United Nations, Department of Economics and Social Affairs, Population Division, last modified April 26, 2012, http://esa.un.org/unup/.

the globe`s surface area – lives one third of the world's population. These 2.5 billion people, whose number is expected to increase to 3.4 billion by 2025[2], place very high pressure on global environmental sustainability. As urban populations grow, so does the demand for materials and resources to support them. Where such resource demands were once satisfied by local and regional hinterlands, they are increasingly global in scale and reach. Reinforced concrete is today the most-used construction material worldwide, even in territories where, for lack of resources or know-how, such material is not and cannot be produced.

The last century has seen an unprecedented transfer of products and predefined solutions – instead of capacity-building programs – from the Global North to the Global South, under the rubric of "development aid." The economic incentives for the North are obvious: when developed nations introduce, for example, their reinforced concrete technology – and all the attendant norms and standardizations – to developing nations, those countries must also acquire the proper machinery, the technical expertise to maintain them, and the building materials suitable for those machines, and they must buy all of those things from the North. This phenomenon has generated trans-continental, globe-spanning materials flows and has profound consequences for the sustainability, functioning, sense of ownership, and identity of future cities. The consequence is the division of our planet between those who produce goods and services and develop the means to do so and those who are meant just to consume.

It is impossible to ignore the foreign dominance of the present-day construction industry in Africa. In this situation, the division between producers and consumers is even bolder than just explained: the development of new and innovatively adapted technologies is removed from the agenda completely, as are questions of sustained quality, health impacts, and production circumstances. Imported products and services are momentarily simply more affordable for developing nations than investing to develop their own technologies and human intellectual as well as skill capacities. And why would these countries have an interest in changing this condition by teaching young Africans how to overcome such dependencies by developing their own know-how?

Bamboo has the potential to revolutionize the building sector. This revolution could be driven by developing nations in the tropical zone, which would be a first step towards reversing the old North-to-South trade routes. A material that's superior to the steel conventionally used in the construction sector could be produced and marketed in the South and exported to the North. The preconditions for this would be a willingness and courage on the part of developing nations to acknowledge their great potential and invest in such new technologies and material research themselves, rather than waiting for the North to send prefabricated "solutions" to them. This will require a change of mentality and the establishment of research capacities as well as better systems to protect intellectual property rights. Real development aid – instead of just shipping products produced and protected in the North – will also be crucial to sustain these changes and reverse the status quo.

---

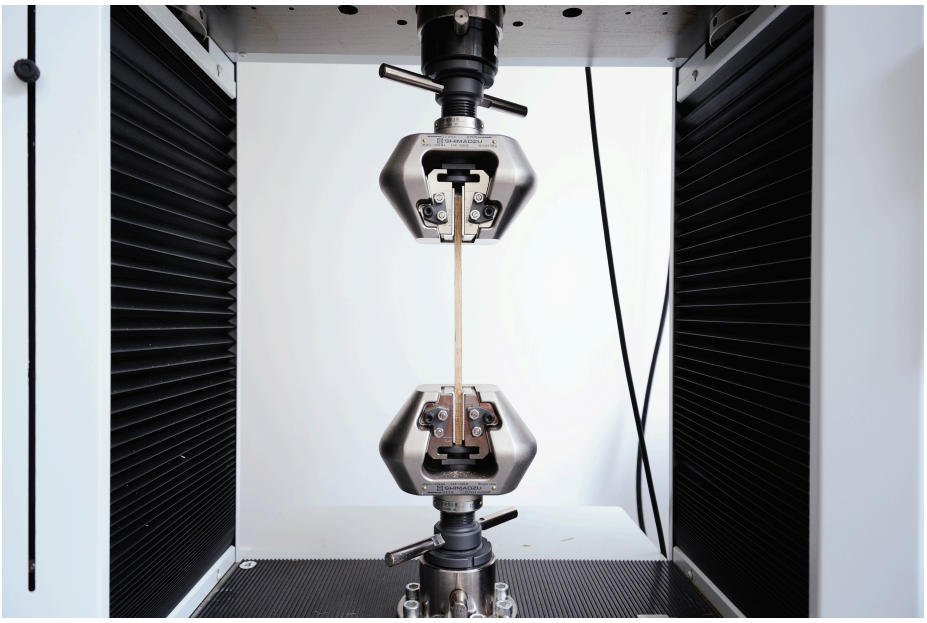
[2] United Nations, Department of Economics and Social Affairs, Population Division. On-line Data: Urban and Rural Population http://esa.un.org/unpd/wup/unup/index_panel1.html

Our homogeneous, world-spanning building industry no longer asks the most obvious questions: What materials are locally available? How can I utilize them in the construction process? We need to start research projects with local universities and other institutions, such as vocational training centers or material testing operations. Developing nations themselves do not devote enough attention or resources to exploring these questions and developing local solutions. Instead, a catalogue of engineered answers dominates our thinking and doing, suppressing any possible inventions or progress towards alternatives. The project for urban sustainability must be global in ambition, but it cannot be a matter of applying a universal set of rules. Rather, sustainability requires a decentralized approach that both acknowledges the global dimension – climate change, for example – and is, at the same time, sensitive to the social, cultural, aesthetic, economic, and ecological capacities of particular places to thrive and endure. We believe that the most common plant growing in the developing regions of our planet will play an important role in future economic and environmental sustainability if it is effectively utilized by the building industry.

Works cited:

World Urbanization Prospects, the 2011 Revision. United Nations, Department of Economics and Social Affairs, Population Division. Last modified April 26, 2012. http://esa.un.org/unup/.

United Nations, Department of Economics and Social Affairs, Population Division. On-line Data: Urban and Rural Population http://esa.un.org/unpd/wup/unup/index_panel1.html




SHIMADZU