The Implementation of Structural Bamboo as an Alternative to Steel and Concrete in Developing Countries

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

With an ever-growing industrialization of the planet, the need to better protect our planet is essential. Climate change will have damaging effects on our daily lives. Rising tides, extreme weather conditions, damaged environments, plastic pollution, increased carbon emissions, and more all contribute to or result from our mismanagement of innovation (NASA, 2021). Each sector must strive to correct its wrongs. So, how can a structural engineer help? Structural engineering is a stagnant field. Concrete and steel have been a staple of the industry due to the material properties, capacity, and cost. Buildings and building construction contribute to nearly forty percent of energy demand and carbon emissions relating to energy demand (Sheikh, 2022). With such a large footprint, structural engineering must become the forefront of sustainability.

How can concrete and steel be supplemented? How can the impact of said materials be reduced? While both materials have made progress in reducing their carbon footprints, alternatives exist (Shapiro, 2020). Mass timber has become a newly engineered product that looks to compete with the two. Mass timber is engineered timber beams made from wood, a more sustainable practice than manufacturing steel and concrete. Sustainable alternatives to structural steel and concrete can be found elsewhere, too. The industrialization of the United States and other global leaders made us believe that concrete and steel are the only way forward. Around the globe, materials like adobe and bamboo can still serve as a purpose for structures (Costa et al., 2019). Structural engineers must analyze these alternatives to reduce the carbon footprint created by the construction and usage of buildings.

Construction projects lend themselves to unsustainable practices. Not only can the design be unsustainable, but the procurement of materials, the waste generated by the workers, and the handling and storage of materials all contribute to producing unsustainable waste (Nagapan et al., 2011). Material waste, environmental displacement, and carbon emissions from the erection of the structure also contribute to the carbon footprint. Poorly constructed structures also require more maintenance, which results in a larger carbon footprint.

Climate change will cause irreversible damage without us providing a sustainable solution. Structural engineers can contribute to change by utilizing sustainable alternatives to structural steel and bamboo, utilizing locally sourced materials, and reducing the carbon emissions that result from the construction practice.

Background and Significance/Motivation

Buildings and structures disturb the existing environment. That much is clear. But why? Structures destroy natural vegetation, displace the creatures' habitats in the environment, displace water runoff, increase noise, light, and regular pollution, and more (Schultz, 2014). Once the structure exists, the surrounding land is gutted to fit water, gas, and electricity pipes that further destroy the environment. The energy required to maintain said building often is not from a renewable source either. Almost 60 percent of Americans use natural gas to power their homes (Lawrence & Berry, 2017). While natural gas generates less carbon emissions than petroleum or other fossil fuels, it still is a nonrenewable resource.

Looking at alternative materials like mass timber, how is it more sustainable? Smelting iron ore and combining it with other alloys to make structural steel emits 1.4 tons of carbon emissions (Tiseo, 2023). Acquiring materials to make concrete also contributes heavily to greenhouse gas emissions. Concrete comprises three main components: aggregate[1], cement, and water. The acquisition of aggregates requires the mining of rocks, and the mining tools are often petroleum-fueled. The steel industry has pushed to become more sustainable using recycled structural steel. Over 90 percent of new structural steel members contain recycled steel (Steel, n.d.). However, recycling still requires the smelting of the component, which, in turn, releases greenhouse gases from the required high heating. The concrete industry moves at a much slower pace. Mass timber reduces net carbon usage by tackling the issue of both previously stated materials by focusing on material acquisition. Trees are a renewable resource. If mass timber manufacturers replant the trees, mass timber on paper provides a more sustainable solution than traditional structural materials.

So why isn't mass timber being applied universally? Mass timber is supposed to offer a cheap alternative due to the relatively low construction cost (HKS, 2022). The transportation of mass timber members is also said to be cheaper since the material is lighter. Lighter and smaller loads mean fewer trucks transporting. Fewer trucks mean fewer carbon emissions because of transportation. Manufacturing requires large trees that are not grown in every region, and greenhouse emissions increase when exporting components from the northwest regions of North America. The material is new, and the long-term effects of larger structures are unknown. Wood shrinks more than concrete due to moisture content evaporating (Reeb, 1995). As a result, anything above five floors is uncertain due to the contraction of wood. People are nervous about wood structures as well. Compared to concrete, wood does not burn at a predictable rate. Mass timber also claims to facilitate construction due to the smaller and lighter components. Since the material is new, few construction workers know how to build around it, and extra training is

[1] Aggregates are granular materials like rock used in concrete mixes.

required to adjust to the new construction methods. All the extra labor and transportation only drive up the carbon footprint, thus presenting whether mass timber is more sustainable.

Other alternatives lack the momentum to compete with steel and concrete. Adobe and structural bamboo can be used for smaller structures worldwide, but they lack the properties for superstructures like skyscrapers.

Engineers can take inspiration from these designs. Reducing the carbon footprint does not mean reinventing the wheel. A sustainable solution can be to look at locally sourced materials. That reduces the emissions that come with the importation of resources. The footbridge I am designing in Pocona, Bolivia, utilizes mostly all materials, except for the steel wires that go across the footbridge, which are locally sourced.

Bamboo can provide a locally sourced material found around the world. Accessibility will provide a cheaper cost and a potential alternative to traditional steel and concrete, especially in areas where new construction costs impact the community more.

Methodology

Literature Review

The literature review will analyze documents that answer whether structural bamboo is feasible as an alternative to steel and concrete. The properties of bamboo will be analyzed. The research will also analyze how sustainable practices were successfully implemented in developing countries. Construction means and methods that yield sustainable results. Upon analyzing the two, the discussion will center on implementing structural bamboo in developing countries, focusing on Bolivia, which is related to the footbridge project organized by Engineers in Action. Finally, the literature review will answer the research question by discussing technological momentum and why we need sustainable development.

Interview

To gather more information, I will interview Bridgette Larsen. Bridgette is a Peace Corps volunteer serving in Fiji. She currently resides in Vanuakulu, in the Naitasiri Province. Bridgette has completed one year of her two-year volunteering. Bridgette collaborates closely with the residents to implement a sustainable design, such as solar streetlights. She is to report on the entire implementation process. The interview will provide a first-person perspective of sustainable design in developing countries. As previously stated, to properly utilize sustainable alternatives to structural steel and concrete, we must see what makes a design sustainable. The interview will focus on the cultural gap between developing and developed countries regarding sustainable design. How does a country like Fiji add solar energy into their daily life? Are the residents involved in the implementation? Do the locals know how to maintain the design? Do all parties understand the total carbon footprint of this project? The cultural lag is significant because understanding where the differences are when implementing sustainable designs in developing countries will help us understand where we can improve.

Case Study

Locally sourced materials reduce the overall carbon footprint in the construction of buildings, too. Engineers in Action is a nonprofit organization that designs bridges and provides water infrastructure in developing countries (Engineers in Action, 2023). Engineers in Action, or EIA, partner with universities to provide students with the opportunity to work towards those developments by tasking the student chapters at each school to design the needed product. The partnership with the University of Virginia tasks students with designing a footbridge for a rural community. In the academic year 2023-2024, students were assigned the Rio K'ellu Mayu pedestrian footbridge in Pocona, Bolivia. Due to the project's remoteness, locally sourced materials are required to build the bridge. That design constraint helps reduce the cost while not increasing the carbon footprint due to the lack of manufacturing and transportation of foreign components. The EIA's footbridge project will be used as a case study to analyze the need for locally sourced materials. The decision to use local stone and other materials for the bridge will be analyzed by focusing on the diffusion of innovation and why the need to use technology available can provide a broader answer to issues relating to global warming.

Literature Review

Literature Review

Research has been conducted for years on the material properties of bamboo. Bamboo is not a new building material. Bamboo is light but highly flexible. Due to its flexibility, the bamboo stock has a high tensile strength (Awalluddin et al., 2017). Tensile strength means the material can be stretched under stress and return to its original structure without fracture, meaning it is elastic. Another extremely elastic material that performs well under tensile strength is steel (with its many iterations). In modern buildings in the United States, most buildings are either reinforced concrete, prestressed concrete, or steel, all containing steel; 46 percent favor steel and 34 percent for reinforced concrete (AISC, n.d.). Steel maintains the integrity of the field by allowing flexibility in large loads. As a result, bamboo can be a sustainable alternative to steel, sharing similar material properties with a more lightweight material.

Structural bamboo has popular potential usages as reinforcement in concrete or as an alternative to structural steel. Reinforced concrete is concrete with steel bars acting in the tensile strength to take on the tension acting on the beam. Concrete is weak in tension (Ganiarachchi, 2023); thus, adding what is known as rebar extends the life and allows higher stresses to act on the beam. Instead of steel, bamboo, with its high tensile strength, could be used. Bamboo as rebar could work for lower-load structures (Ogunbiyi et al., 2015). The desired composite design of both bamboo and concrete does require chemical adhesives. That added chemical introduces potential waste or runoff in the creation of the material. No life cycle analysis was done in the research. However, the adhesive, epoxy, is made from petroleum materials, increasing the overall carbon cost and potentially hurting the local ecosystem where the practice could be implemented (Guy, 2023). The other alternative is bamboo, acting alone as the structural member holding all the load. The tensile strength provided by bamboo is comparable but has a fatal flaw (Ogunbiyi et al., 2015). The reason structural engineers chose steel was because of its failure. Steel does not suddenly snap or crack like concrete does. The failure mode can be visibly seen. The member deforms heavily before complete failure. Bamboo lacks that. When pushed to the ultimate capacity, the bamboo undergoes brittle failure. It has a low elastic modulus, meaning that once under extreme loads, it cannot return to its original state. They recommend not using bamboo as the primary structural member, but it could be used as an alternative for roofs or partition walls.

Engineered bamboo can provide long-term solutions rather than just bamboo as rebar or a member. GluBam and Lamboo provide that median. GluBam is bamboo stocks glued together in cross sections to form beams, and Lamboo is laminated cross-sectional bamboo beams (Xiao, 2022). The engineered structures can support higher loads, thus providing a more comprehensive range of structure types. Not enough research has been done in large-scale testing. Much of the research is based on mass timber design, usually cross-laminated timber. The brittle failure presents a significant issue. On top of the uncertainty, bamboo structures must be maintained more often than steel structures (Xiao, 2022)—more inspections, reapplication of chemical adhesives, etc. Maintenance requires more materials to repair, increasing the life cycle carbon cost. Maintaining such structures requires extensive treatment that developing countries often cannot provide.

Bamboo also does not have the same carbon footprint as steel or concrete. The production of steel requires high energy input and output. The high heat required to melt the steel and constant ore mining do not provide a low carbon cost. The acquisition of materials for steel far outweighs the carbon cost compared to bamboo. Concrete comprises aggregates, cement, and water. The acquisition of aggregates requires mining such material, driving the cost up. Bamboo is again readily available. The engineered product drives up the overall cost and potential maintenance.

The application of bamboo in developing countries provides another obstacle. Providing engineered bamboo sounds excellent as the local material is abundant, especially in Bolivia. Yes, simple structures can be built utilizing regular bamboo, but engineered bamboo requires teaching locals about the production, construction, and post-construction. The right engineered tests would be required to ensure the bamboo can sustain heavy loads, serviceability checks, etc. Bolivia has building codes, but structural bamboo building codes do not exist even in the United States. There are international building codes for bamboo structures (Li, 2019), but those emphasize engineered bamboo. Construction is also different in developing countries. Safety requirements, regulations, and laws are in place in the United States to ensure safe practices. The pre-and post-conditions of construction are also well-regulated. In developing countries, similar practices apply for construction but not post-construction. Once the project is delivered, developers and engineers do not inspect as often as they should, if at all. Teaching communities how to maintain these sustainable designs will create an environment of self-fulfillment and independence (Pocock, 2016). A long-lasting solution and a plan will ensure that the sustainable solution is not misused. Nevertheless, you must instruct people who may not fully understand this field. The relationship is built on trust, not regulations. In the following data review, we will see the development of sustainable design in a developing country without much regulation.

Interview

We turn to a real-world scale project to further understand how to implement sustainable design practices successfully. Bridgette Larsen is a Peace Corps Volunteer serving in Fiji, in the Vanuakulu, Naitasiri Province. In partnership with the Peace Corps and USAID, solar streetlights were installed. Solar streetlights were placed to provide more security for residents when traversing at night. The project has been a success, but Bridgette has claimed that the lack of accountability has resulted in a misused cash influx. Fiji has a new government as of 2020 that has been investing in the country itself. In the case of the solar streetlights in Fiji, the progress was slow due to the misuse of funds. Her work is under the World Bank project through the Ministry of Finance, and they wish to tackle climate change projects at the village level. They receive a grant of $20,000 but do not check in to see how the projects are progressing. Thus, Fiji uses volunteers to bridge that gap. However, the success of the project cannot be undermined. The local community was provided with a sustainable design that the local community themselves saw the need and built.

Case Study

As previously stated, Engineers in Action provides students with the opportunity to design a footbridge in a developing country. All the resources are locally sourced except the steel suspension cables. The cables are by far the most expensive item. All stone, cement, fencing, etc., is made or bought in the designated country, Bolivia or Eswatini. Engineers in Action wish to serve rural communities. Designing a footbridge with Portland cement and high-tensile strength steel is straightforward. However, that is not feasible for a rural community of 220 people near Pocona, Bolivia. So, EIA chooses to source locally for that very reason, driving down the cost. Locally sourced materials also reduce the carbon footprint. If we analyze a project as a life cycle analysis, meaning calculating the total carbon footprint from production to decommissioning, we see that using local materials is excellent. There are no high transportation emissions if you are not importing your material. Using locally sourced materials can help achieve carbon-neutral structures.

Discussion/Results

Literature Review

The technical review of the research aimed to determine the feasibility of structural bamboo. While possible, we must factor in another aspect. How comfortable is anyone in a house made from flimsy bamboo? Xiao's research also addresses these concerns. The research investigated the application of structural bamboo with seismic loads and fire performance. Simulations indicate that structural bamboo walls can perform well but have not been experimented with yet. The fire was experimented with, and remarkable results were obtained when the bamboo was treated. Like mass timber, GluBam is treated by charring the outside layer, creating a protective cover (Xiao, 2022). Both experiments wish to address the serviceability issues.

All the research indicates that structural bamboo is feasible as an engineered product with low-load scenarios. When steel is not available, bamboo could be used as an alternative. However, bamboo must not act as the only structural member. Engineered bamboo also poses a new problem: added carbon cost. Engineering Glulam and bamboo as rebar both require chemical adhesives. Both cannot be made at the project site location. They must be manufactured and processed at a facility that adds carbon emissions from the transportation of the components. The performance will not hold up as well and will require continuous maintenance. In developing countries, there already exists a lack of technical expertise in inspection. Adding more structures that need these inspections will only hurt.

Technological momentum refers to how technology and society mutually influence each other. The research focused on the feasibility of a sustainable alternative to steel and concrete. The research is intended to focus on why there is a need to shift. With global warming, how are we solving issues in the built environment? Focusing on alternative structural materials provides a possible solution. The need for sustainable development directly relates to society's explosion of energy consumption and carbon emissions. Because we are at the beginning of sustainable development, we must ensure we can provide feasible universal solutions. Once the technology matures, it will be so ingrained into society that it has little control. Engineers must design to avoid this technological momentum.

Interview

Sustainable design requires suitable construction methodologies as well as design. Installing solar panels or a locally sourced bridge is excellent. Poor maintenance requires new materials and manufacturing, increasing the total carbon footprint. The industry is now open to the discussion of life cycle analysis, viewing the entire project from cradle to casket. Applying those ideologies to these projects can facilitate sustainable design further. And we can apply that to a larger scale. Having mass timber is great, a “sustainable” material that is made from a renewable resource. Having solar panels in rural Fiji is great. However, it includes the emissions from the transportation of each component, the manufacturing carbon footprint, and the carbon cost from maintenance. Now, you can assess the total carbon cost and address more tangible sections. This means reducing the cost of transportation, using renewable energies to manufacture your product, utilizing local resources, and creating a sustainable design. Nevertheless, with the push for change, we see government entities also wanting to strive for sustainable development. Funding is always an issue when tackling these issues. Sustainability is often associated with a high upfront cost. Government funding can remove that connotation.

Case Study

Engineers in Action choose the most cost-effective option because importing materials accessible only to a foreign organization does not help the local community involve themselves. Choosing to go the route of a traditional footbridge with imported resources ostracizes the community. They will not have access to the materials when the bridge requires maintenance. Building the footbridge with the local community will teach them how it was constructed and what to look out for in maintenance. The sustainable solution was locally sourced materials because it is the best economical, social, and environmental choice.

Conclusion

Both the case study and the interview provide a broader sustainable context. Reducing the carbon footprint by using renewable energy is not enough. As seen in the footbridge, utilizing locally sourced materials reduced the overall carbon footprint and cost. The cost helped the local Pocona, Bolivia community afford the design. Regulation is needed in the development and maintenance of the project as well. The solar lamplights provide visibility to the residents of the Naitasiri Providence. The lights were added to help locals access markets at night to provide more safety. The lights are powered by solar energy. Renewable energy is inherently a sustainable design. The implementation of the project required additional government funding. The project was delayed due to a lack of regulation. This highlights the need for regulation in sustainable development.

Structural bamboo can be a sustainable alternative to steel and concrete if regulation exists. The material can exist as a structural member, albeit limited by its capacity. The material is new as a building material when engineered. However, since it can be locally sourced, it provides a sustainable alternative. Bamboo can be utilized for lower-capacity loads. The bamboo can be engineered to sustain higher loads. The engineered product introduces adhesive chemicals that could damage the environment. Regulations for those chemicals must be established to design the engineered structural bamboo properly. Bamboo presents itself as a possible structural design member when adequately regulated. As a result, bamboo can work as an alternative to steel and concrete in developing countries. The regenerative material provides a cheap and alternative solution.

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