CONCRETE CANOE DESIGN

SUSTAINABLE CONCRETE TECHNOLOGIES IN CONSTRUCTION

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Civil Engineering

By
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October 10, 2024

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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

Concrete is a staple in construction, known for its durability and strength. Although not seen for any buoyant aspects, applying it as the primary material for building a canoe, a structure that must be lightweight, buoyant, and maneuverable, is the goal that is not new, but improving upon previous design is what my team is trying to aim for. This goal lies at the center of our capstone project, which aims to develop a form of concrete that retains its characteristic strength while being light enough to float. To achieve this, we are not only exploring a new, innovative concrete mix but also experimenting with optimized shapes and advanced post-tensioning techniques to enhance its resilience. Delving as well into the adoption of sustainable concrete innovations in the construction industry by examining 3D printing, recycled materials, and studies that reduce environmental impact. This work is crucial for grasping the broader implications of integrating disruptive technologies into established practices, as well as ensuring their longevity and success within current frameworks

Technical Topic

Concrete is a material commonly seen in buildings and sidewalks, renowned for its strength and longevity, and "one of the world's most widely used materials" (Nair et al.). However, crafting something like a canoe, which needs to float and maneuver easily through water, presents significant challenges. Typically, concrete is heavy and prone to cracking when it bends or stretches. For our capstone project, we aim to address these issues by transforming traditional concrete into a new, upgraded version that is lightweight, strong, and buoyant enough to serve as an effective canoe construction material.

One of our primary innovations for the concrete canoe project is the development of a post-tensioning system designed to enhance the material's performance under various stresses. This technique involves placing a rubber tube inside the concrete sections before the material sets. Once the concrete has hardened, we introduce a threaded rod into the tube, which is then tensioned. This tensioning process involves hex nuts placed at each end of the rod along with washers, that would be used in turn of a bearing plate so as to not damage the concrete after tightening. This then compresses the concrete and significantly increasing its strength and flexibility. This modification enables the concrete to withstand larger loads and absorb impacts or collisions with the least amount of cracking or sustaining other types of damage if any, making it more resilient in the dynamic environment of water.

Another challenge we face is ensuring the canoe can move smoothly and swiftly through the water, which requires careful consideration of the canoe's shape. We are tackling this by designing and analyzing the shape of our canoe hull, formulating curve equations, modeling the canoe in CAD, and performing structural calculations and FEA. CAD, or Computer-Aided Design, allows us to create precise digital models of the canoe, enabling us to visualize and refine its shape. FEA, or Finite Element Analysis, is a method used to predict how the canoe will react to forces, helping us assess its structural integrity and optimize the design. We are also experimenting with different hull designs in a water channel setup, known as a flume, to observe how water flows around each shape. This testing is essential for determining the most effective hull design that will allow the canoe to navigate through water with ease and provide the stability needed to prevent capsizing, ensuring both performance and safety in the competition.

We are also experimenting with various concrete mix formulations. One approach involves incorporating fly ash into the mix, which helps create a lighter yet durable material. The integration of fly ash into concrete production is a promising development in the pursuit of sustainable construction practices. Fly ash, a byproduct of coal combustion, can be used as a partial substitute for Portland cement, helping to reduce the environmental impact of concrete (Wesche, 1991). We conduct specialized tests to evaluate the flexibility and strength of each mixture, allowing us to fine-tune the blend for an ideal balance of lightness and resilience. Another exciting aspect of our project is the integration of 3D printing technology. Since the concrete canoe competition requires the model to be replicated up to 100 times, we are exploring how 3D printing can streamline this process. Our plan involves designing a mold that allows the canoe's outer shell to be printed from the bottom up, ensuring it retains its shape without collapsing. The canoe would then be printed in sections, which will then be assembled and held together using the post-tensioning system, allowing us to achieve stability uniform assembly in our production.

STS Topic

The practices in construction, even solely focusing on concrete, are influenced by plenty encompassing policies, cultural norms, and environmental considerations. These factors collectively create a sociotechnical environment that begs the question of whether these systems can facilitate or hinder the adoption of innovative, sustainable concrete practices within the construction industry. To address this, we can take two approaches: one focuses on the technologies used in construction and how they contribute to the sustainability of concrete, which delves into the second point of examining the progress being made toward developing a greener concrete mix that supports sustainability either in production or throughout its lifecycle.

One promising technology advancing sustainable practices in construction is 3D concrete printing, that can also be classified as an additive construction by extrusion (ACE). This method enables efficient, material-saving approaches to building with concrete, offering benefits such as reduced formwork and lower labor costs, both of which contribute to a smaller environmental footprint. By optimizing materials and reducing waste, 3D printing has the potential to reshape how sustainable practices are implemented within the construction industry. The mix designs used in 3D printing are specially formulated to achieve the required flowability, or rheology, essential for being pumped and deposited through the 3D printer nozzle. Despite potential challenges in structural sturdiness due to limited fiber content, since smaller nozzle sizes may limit fiber application used for further reinforcement, there can still be specific formulation of these mixes that allows for high strength and stability. Some mixes can consist of partially replacing cement with limestone powder. These mixes reduce carbon emissions while maintaining durability through optimized additives, including chemical retarders and accelerators. This approach creates a "robust and sustainable binder" suitable for 3D printing applications, providing a balance between workability and solid, strong construction (Sanjayan et al., 2019).

Then exploring the intersection of this technology and mixes is essential for understanding the broader implications of integrating sustainable solutions. There are various factors in mixtures that then come to light focusing on the sustainable aspect. With the industry facing pressure to minimize its environmental footprint, one promising approach to an improved upon mixture involves incorporating construction and demolition waste (CDW). Introducing CDW into concrete production in an environmentally friendly manner is seen though Munir et al. As they show this through a life cycle assessment (LCA) that examines CDW-based geopolymer (GP) mortars; an alternative to traditional cement. Their findings indicate that these geopolymers produce nearly 60% less carbon emissions and consume less energy compared to conventional concretes. Such insights are crucial for bridging the gap between technological advancements and practical, sustainable applications, promoting wider adoption of these innovative materials.

This leads us then to the critical role of awareness. Jahren, referencing R. N. Swamy, highlights awareness as one of the most essential driving forces in the concrete recycling process. This idea extends to construction technologies as well; when new technologies are not widely known, it becomes more challenging to leverage them for sustainable innovations in the industry. He argues that fostering awareness of sustainability issues, emission challenges, and recycling has been a major catalyst for the current revitalization in concrete technology development. Also suggesting that the obstacles to adopting sustainable concrete practices may stem more from a lack of industry-wide understanding and commitment than from technical limitations. Awareness has the potential to drive this shift, promoting sustainable alternatives and decreasing dependence on newly extracted resources (Jahren, 2014, p. 190).

As mentioned by Franz-Josef Ulm in a lecture, “There's no way to achieve [greenhouse gas emissions reduction related to cement and concrete production] without new technology and innovation” (Films for the Humanities & Sciences (Firm) & Infobase, 2009). Pellegrino and Faleschini (2016) emphasize the necessity for supportive regulations and market acceptance to fully harness these benefits. They presented that there are technical challenges and potential advantages of incorporating recycled materials into concrete. Pointing out that there is limited evidence documenting the environmental benefits, of using recycled components in new concrete formulations, underscoring the need for more comprehensive research and validation to strengthen the case for these sustainable practices. For so long, the prevailing perception among the general public has been that concrete is inherently harmful to the environment. Recognizing this need for change is a powerful first step that has in way been met, but true progress requires turning this awareness into concrete actions that establish sustainable standards across the industry.

Exploring current innovations in concrete mix development is essential, particularly at the initial stages, as these early interventions can significantly enhance sustainability in the long run. However, it is equally important to consider the sustainability of concrete post-production. Efforts should focus on reusing existing concrete in the production of new concrete or on ecofriendly methods for its disposal. Advancing both early-stage development and post-production processes will support a more sustainable approach to concrete use throughout its lifecycle. While multiple modifications can enhance the strength and functionality of concrete, opening up for more sustainability is paramount. Approaches that have been seen thus far include Singaravel et al. (2024) who delve into enhancing concrete sustainability through the incorporation of waste tires. Observe then that adding recycled rubber and steel fibers to concrete not only improves its sustainability but also significantly enhances its properties compared to traditional concrete. Additionally, the work of Roque et al. (2022) on integrating innovative materials in drainage structures exemplifies how advanced materials in geotechnical applications can help conserve natural resources and reduce construction and demolition waste in landfills.

Conclusion

Our project challenges conventional uses of concrete by creating a lightweight, buoyant material for constructing canoes, which expands the potential applications of this essential construction material. By combining technical innovation, such as optimized concrete mixes, post-tensioning systems, and 3D printing, with an analysis of the sociotechnical landscape, we aim to bridge the gap between material science and real-world industry adoption. Our research not only explores the structural possibilities of sustainable concrete but also addresses the critical social, regulatory, and economic factors that impact the integration of such technologies in construction. Through this dual focus, we hope to provide valuable insights into optimizing material properties for environmental sustainability and fostering a market that actively supports eco-friendly innovations. Ultimately, our work aims to advance sustainable practices in construction, contributing to solutions that address the industry’s environmental impact and align with long-term sustainability goals.

References:

Films for the Humanities & Sciences (Firm), & Infobase. (2009). Breaking the Wall of Concrete: How Green Concrete Can Reduce the Giant Carbon Footprint of Construction. New York, N.Y.: Infobase.

Jahren, P., Sui, T., & Ebook Central - Academic Complete. (2014). Concrete and Sustainability. Boca Raton: Taylor and Francis, CRC Press. pp.181-224

Makul, N. (2023). Recycled Aggregate Concrete: Technology and Properties. Boca Raton, FL: CRC Press.

Munir, Q., Lahtela, V., Kärki, T., & Koivula, A. (2024, August 1). Assessing life cycle sustainability: A comprehensive review of concrete produced from construction waste fine fractions. Journal of Environmental Management, 366.

Nair, K., & Anand, K. B. (2024, October 1). Sustainability of alternative concretes: emergy and life-cycle analysis. Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 177(4), 217 - 229.

Pellegrino, C., Faleschini, F., SpringerLink (Online service), & Ebook Central Sustainability eBook Subscription. (2016). Sustainability Improvements in the Concrete Industry: Use of Recycled Materials for Structural Concrete Production. Springer International Publishing. pp 107-138.

Roque, A. J., Da Silva, P. F., & De Almeida, R. P. M. (2022, November 1). Recycling of crushed concrete and steel slag in drainage structures of geotechnical works and road pavements. Journal of Material Cycles & Waste Management, 24(6), 2385–2400. https://doi.org/10.1007/s10163-022-01486-7

Sanjayan, J. G., Nazari, Ali (Materials scientist), Nematollahi, B., & Knovel, A., C. E. &. C. M. (2019). 3D Concrete Printing Technology: Construction and Building Applications. Oxford [England]: Butterworth-Heinemann.

Singaravel, D. A., Veerapandian, P., Rajendran, S., & Dhairiyasamy, R. (2024, February 26). Enhancing high-performance concrete sustainability: Integration of waste tire rubber for innovation. Scientific Reports, 14(1), 1–17. https://doi.org/10.1038/s41598-024-55485-9

Wesche, K., & Ebook Central - Academic Complete. (1991). Fly Ash in Concrete: Properties and Performance. New York: Spon Press [Imprint]. pp.160-178.