PADDLING TOWARDS SUSTAINABILITY: REDESIGNING CONCRETE CANOES FOR THE ENVIRONMENT

HARMONIZING TECHNOLOGY AND ENVIRONMENT: THE JOURNEY OF SUSTAINABLE CONCRETE CANOES

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By
Jason Wong

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Technical Team Members:
Ethan Ames
Madison Cannon
Melody Cao
Leon Crawford
Kenneth Reyes

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.

ADVISORS

Rider Foley, Department of Engineering and Society

Ryan Henry, Department of Civil and Environmental Engineering

Introduction

In the tapestry of human construction, concrete emerges as a quintessential material, lauded for its strength, versatility, and longevity. Holding the status of the second most widely used substance on Earth after water, concrete stands as the most heavily consumed material in the construction sector (Knoeri, Sanyé-Mengual, & Althaus, 2013). Data from the Global Cement and Concrete Association (GCCA) reveals a significant rise in cement production: from 4.2 billion tonnes in 2020 to a projected 9.8 billion tonnes by 2050 (Global Cement and Concrete Association, 2023). This widespread use casts a shadow of environmental concerns, primarily due to the significant carbon footprint and resource consumption associated with concrete production.

Amidst these concerns, the Committee on Concrete Canoe Competitions (C4), a branch of the American Society of Civil Engineers (ASCE), is currently exploring the possibility of producing 100 concrete canoes to support regional lake and river transportation throughout the United States with an emphasis on sustainability and environmental impact. The task of producing these vessels has been assigned to competitors. In response, C4 invites pre-qualified ASCE student chapters, hereinafter known as "Teams," to participate in this Request for Proposals (RFP).

Teams are tasked with designing and building a prototype concrete canoe, along with a product display featuring relevant information on the canoe's design, materials, fabrication, and durability. Teams are also mandated to deliver a technical proposal and presentation to a panel of judges. These submissions are used by the judges to evaluate the innovative design, aesthetic, cost, and paddling performance of the product. Finally, the canoe will undergo testing in a series

of races to demonstrate its performance in the water (ASCE Committee on Concrete Canoe Competitions, 2023).

The history of the Concrete Canoe dates back to the 1960s when a few ASCE Student Chapters began holding intramural concrete canoe races, laying the groundwork for the esteemed competition we know today (American Society of Civil Engineers, 2023). First officially held in 1988, the ASCE Concrete Canoe Competition is a unique and renowned event within the civil engineering community. It serves several essential purposes, including promoting innovative engineering solutions, fostering collaboration, and enhancing knowledge of concrete technology. Such competitions are instrumental in shaping the skills and creativity of future civil engineers, who play a pivotal role in designing and maintaining the safe, functional, and sustainable structures and infrastructures that society relies upon daily.

The competition serves as a multifaceted platform that not only challenges civil and general engineering students but also addresses the pressing needs of the civil engineering profession, including innovation, sustainability, teamwork, and networking opportunities. In 2003 a survey was conducted by students at the Rochester Institute of Technology assessing the impact of the Concrete Canoe and Steel Bridge Competitions on 100 civil engineering students, both past and present, and found that participants of the competition reported having greater ratings of individual leadership, teamwork, oral communication, design and construction, and project management skills and feeling more confident, exposed, and enthusiastic compared to non-participants (Aghayere, 2003).

This paper delves into the technical design, as well as the complex interplay between the environmental challenges posed by concrete and the potential avenues for creating a more eco-friendly and sustainable form of concrete.

MIX DESIGN BREAKDOWN

The University of Virginia team, *Look 'Hoos Back*, has defined this challenge into three key divisions: Hull, Construction, and Mix. As the captain of the Mix Design team, my role is to formulate the optimal concrete blend, ensuring its performance meets competition specifications while balancing strength, weight, and buoyancy. Concrete canoe construction demands a precise mix design to meet specific structural and performance requirements. It involves factors such as material composition, curing processes, and engineering calculations to ensure buoyancy, stability, and structural integrity. The technical challenge lies in optimizing the mix design for both performance and sustainability. In the context of a concrete canoe and its performance, specific gravity, density, and compressive and tensile strength are critical factors that engineers and teams participating in concrete canoe competitions consider.

For various applications, the current design of concrete mixes includes, cementitious materials, both primary and secondary, such as Portland cement, which is produced by heating a blend of limestone, clay, and other substances in a kiln (Portland Cement Association, 2023). Aggregates, including coarse options like crushed stone and fine alternatives like sand, play a crucial role by providing structural strength and filling voids (Penn State College of Engineering, 2019). Water is indispensable for initiating cement hydration. Additionally, admixtures, such as plasticizers (water reducers) for enhancing workability, retarders for adjusting setting times, accelerators for faster setting, and superplasticizers for improved flow and reduced water content, are often integrated into the mix. The overall framework of concrete's life cycle assessment (LCA) is illustrated in Figure 1.

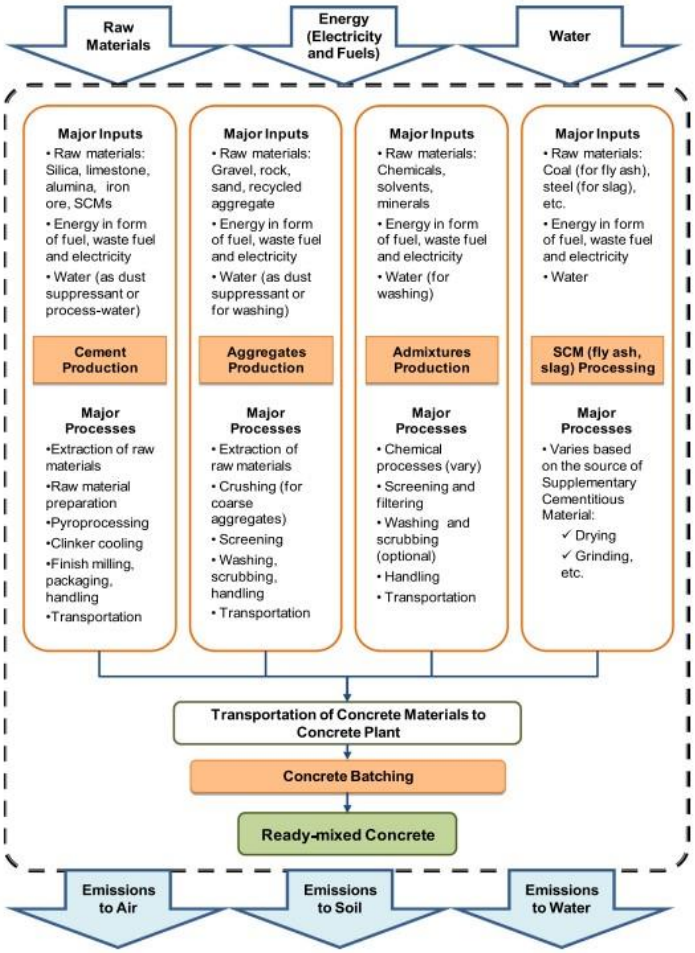

Figure 1. Diagram of the overall framework of concrete's LCA (Petek Gursel, Masanet, Horvath, & Stadel, 2014)

Different combinations of materials within these categories can result in concrete mixes with varying properties. For example, the use of high-performance aggregates can lead to concrete with exceptional strength and abrasion resistance, making it suitable for bridge beam repair and the construction of wind turbine towers (Akhnoukh & Buckhalter, 2021). In essence, concrete mix design is an art and a science that aims to balance components for structural needs, environmental sustainability, and project-specific performance criteria.

For *Look 'Hoos Back*, this year's mix design goal is to create an environmentally sustainable and carbon-neutral blend that aligns with the RFP and its mission. The preliminary mix designs exclude cement due to its significant environmental impact. In 2011, global Portland cement production reached approximately 3 gigatonnes, resulting in roughly 2.6 gigatonnes of annual CO2 emissions. Approximately half of these emissions originated from fossil fuel combustion during production (Petek Gursel, Masanet, Horvath, & Stadel, 2014).

Inspired by Youngstown State University's 2022-2023 mix design, our team explored the possibility of completely replacing cement with hydrated lime and ground granulated blast furnace slag (GGBFS) (Youngstown State University Concrete Canoe Team, 2023). Hydrated lime is a product derived from limestone and is known for its lower carbon footprint compared to traditional cement due to the less intense kiln firing requirement (Bates, 2023). GGBFS is a byproduct of iron production and has similar binding properties to cement but with significantly reduced environmental impact (Cahyani & Rusdianto, 2021). Both materials offer eco-friendly alternatives to cement, reducing carbon emissions associated with concrete production while maintaining structural integrity. Additionally, we integrated environmentally friendly materials, such as a lightweight foamed glass aggregate crafted from 99% recycled glass, a naturally occurring expanded shale lightweight aggregate, and various admixtures to enhance workability and air entrainment in the concrete mix. Using these materials is an eco-conscious approach that aligns with our commitment to sustainability and environmental responsibility. The design details are presented in Table 1.

Table 1: Mix Design Table 001 - Hydrated Lime + Slag (Wong, 2023)

Materials	Volume	Weight	Specific Gravity	Density
Water	6.41	400	1.00	62.40
Superplasticizer	0.03	2.02	1.08	67.39
Air Entrainment	0.03	1.89	1.01	63.02
Hydrated Lime Type S	1.39	200	2.30	143.52
Blast Slag (GGFS)	4.55	800	2.82	175.97
2-4 mm Poraver	5.25	183.45	0.56	34.94
0.5-1 mm Poraver	3.50	80.81	0.37	23.09
Riverlite Arcosa	5.83	262.50	0.72	45.00
Total	27.00	1930.91	1.15	71.52

By actively seeking eco-friendly alternatives and reducing dependence on traditional cement, our team aims to make substantial contributions to reducing carbon emissions and enhancing the overall sustainability of concrete production. This coheres with global sustainability objectives and conforms to the guidelines outlined in the RFP. Although *Look 'Hoos Back* has made considerable strides towards a more environmentally sustainable mix

design, the social aspects of sustainability, such as diversity and interdisciplinary team members, seem to be an area where many concrete canoe teams, including ours, and even the broader field of concrete technology, could improve.

SOCIAL SUSTAINABILITY

Engineering competitions, particularly those as intricate and demanding as the Concrete Canoe Competition, provide a quintessential platform for interdisciplinary collaboration. The need for such collaboration is underscored by the limitations inherent in a homogenous group. The failure of students to engage in interdisciplinary learning in a low-threat university environment could lead to inadequate preparation for real-world challenges where the stakes are exponentially greater. Interdisciplinary experience is pivotal as it brings unique perspectives and mitigates the risk of detrimental phenomena such as groupthink, where conformity can overshadow innovation (Hill et al., 2020).

The Concrete Canoe Competition showcases the potential for interdisciplinary learning and the pitfalls of its absence. In this competition, the diversity of backgrounds and experiences is not just an asset; it's a necessity. Teams like California Polytechnic State University (Cal Poly), despite clinching its seventh national title in 2023, reflect a concerning trend in this regard. Their team predominantly consisted of civil engineering students, with the exception of just one member from a non-civil engineering discipline (Thompson & Steers, 2023). This composition's achievements, while impressive, raise questions about the full spectrum of creativity and innovation that could be unleashed with a more diverse team (Reynolds & Lewis, 2017). It exemplifies the overarching trend in such competitions: a predominance of civil engineering students, which could inadvertently foster a homogeneous environment. Such an environment may not fully leverage the wide range of perspectives and skills that are crucial for

groundbreaking innovation. In the realm of engineering, where the stakes are high and the challenges are multifaceted, the absence of diverse academic backgrounds isn't just a lost opportunity for inclusivity but a potential impediment to progress (Rocha et al., 2022).

The nuanced intersection of social and technical dimensions within engineering competitions becomes especially intriguing when analyzed through the framework presented in Thomas Seager's seminal work, "Sustainable Engineering Science for Resolving Wicked Problems" (Seager, Selinger, & Wiek, 2011). Seager advocates for a comprehensive and interdisciplinary approach to sustainable engineering, urging a harmonious integration of social and technical considerations to effectively address intricate challenges. This requires a shift away from the traditional focus on technical solutions and towards a more holistic approach that considers the long-term consequences of our actions by evaluating the social, environmental, and economic quality improvements said solution would have. His perspective underscores the significance of grasping how diverse social groups perceive and attribute value to technology, shaped by their unique contexts and priorities. Central to Seager's discourse is the concept of "wicked problems," denoting socially embedded issues such as climate change and hazardous waste as being inherently resistant to straightforward solutions due to the involvement of numerous stakeholders with conflicting values and priorities. Seager defined a wicked problem as a complex, interconnected issue that is challenging to designate and solve due to its multifaceted nature, involving various stakeholders with conflicting values and perspectives. They are typically characterized by ambiguity, uncertainty, and the absence of a clear solution. This lens, as applied to the context of the Concrete Canoe Competition being the wicked problem, emphasizes the importance of diverse perspectives in discovering innovative solutions.

For Cal Poly and similar teams, the technological pursuit is likely dominated by a quest for efficiency and speed, reflecting a more traditional engineering mindset where performance metrics are paramount. In contrast, UVA's focus on user experience indicates a broader interpretation, where technology is not just about achieving the best performance but also about ensuring sustainability, usability, accessibility, and perhaps even aesthetic appeal. This approach acknowledges that a canoe, while needing to be fast and lightweight, also needs to be stable, comfortable, eco-friendly, and user-friendly. This compromise is emblematic of how different stakeholders within the same competition perceive and value aspects of technology differently. By considering the perspectives and priorities of all teams, we can gain a more comprehensive understanding of the wicked problem at hand.

This diversity in perspectives enriches the competition, as it brings to the fore different interpretations of what constitutes an optimal concrete canoe. It pushes teams to think beyond conventional metrics and consider a more holistic approach to design and engineering. It also highlights the importance of having diverse teams. A team that includes members from various academic backgrounds and disciplines is more likely to consider these varied aspects, leading to designs that are not only innovative but also inclusive and reflective of a broader range of user needs and experiences (Specht & Crowston, 2022).

Thus, the Sustainable Engineering Science framework not only aids in understanding the different priorities and values of teams in the competition but also underscores the importance of inclusivity and diversity in fostering a more comprehensive and empathetic approach to engineering challenges.

RESEARCH QUESTION AND METHOD

Today, sustainability has become imperative, especially in industries heavily reliant on materials like concrete. This realization leads me to an intriguing research question: How can the concrete mix design be made more eco-friendly and sustainable?

Addressing this question holds profound importance, as concrete is a cornerstone of construction, and enhancing its environmental footprint could have far-reaching impacts. My analysis will primarily involve conducting interviews with Mix Design Captains during the regional Concrete Canoe competition held at Virginia Tech from March 28th to the 30th (ASCE Student Symposium, 2023). An example of a question that I would ask is, “Can you share any experiences where the team faced trade-offs between environmental sustainability and practical feasibility in concrete mix design? How were these challenges addressed?” These captains, with their hands-on experience and expertise, are poised to offer valuable insights into practical, sustainable mix design strategies. The data I collect will be interpreted through the lens of both environmental impact and practical feasibility, aiming to strike a balance that could redefine how we approach concrete mix design in the future.

CONCLUSION

This research aims to revolutionize concrete mix design by making it more sustainable and eco-friendly. The technical deliverable will be a refined concrete canoe design that balances environmental concerns with structural integrity. The STS deliverable will provide insights into how engineering practices can harmonize with ecological imperatives. Completing these deliverables could significantly mitigate the environmental impact of concrete usage in the construction of a canoe, setting a precedent for sustainable engineering. The expected result is

not just a tangible design but a transformative approach, inspiring a shift in societal perspectives towards environmentally conscious construction practices.

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