Paddling Towards Sustainability: Redesigning Concrete Canoes for the Environment

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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

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.

Demands of construction and the surge in urbanization have amplified the environmental concerns related to concrete. Within the realm of construction, the pursuit of sustainability in concrete is a pressing concern, necessitating a delicate balance between functionality and environmental impact. In the context of concrete, sustainability refers to the ability to meet the present needs of greener infrastructure development while promoting environmental quality for future generations. Concrete, while celebrated for its structural prowess, faces inherent challenges on the sustainability front. The production of traditional concrete involves a substantial carbon footprint, with 88% of CO_2 emissions attributed to the energy-intensive process of cement production (Nisbet, VanGeem, Gajda, & Marceau, 1997).

Additionally, the extraction and transportation of raw materials like limestone contribute to the immense greenhouse gas emissions. Researchers are exploring alternative materials and innovative production techniques to reduce the environmental impact of concrete and address these challenges. Sustainable concrete solutions often involve incorporating supplementary cementitious materials, such as fly ash or slag, which can replace some cement content. Moreover, advancements in low-carbon concrete formulations and the development of carbon capture technologies during cement production are promising avenues to mitigate the ecological footprint associated with concrete.

The urgency to make concrete production more sustainable is underscored by the forecasted increase in global cement production (Global Cement and Concrete Association, 2023). As we stand at the precipice of substantial growth in construction activities, research and development in finding the balance between strength, workability, and eco-consciousness becomes paramount. The quest for sustainable concrete is not merely a scientific endeavor. It is a commitment to shaping the future of construction in a way that respects both the legacy of the past and the imperatives of the present and future.

To bridge the gap between academic research and practical application, college students, especially those majoring in civil engineering, have a unique opportunity to contribute to the pursuit of sustainable concrete through participation in events like the American Society of Civil Engineers (ASCE) Concrete Canoe Competition. The Concrete Canoe Competition, organized by the American Society of Civil Engineers, is an annual event that challenges students to design, build, and race canoes made entirely of concrete. The competition format typically involves several components, including technical design reports, oral presentations, canoe displays, and on-water racing. Scoring criteria in the competition encompass various aspects, such as the quality of the concrete mix design, canoe aesthetics, structural integrity, buoyancy, paddling performance, and innovation. Judges evaluate each team's work based on these criteria to determine the overall winner. Qualified judges for the Concrete Canoe Competition often include professionals from the civil engineering field, academia, industry experts, and ASCE members. These judges possess expertise in materials science, structural engineering, concrete technology, and related disciplines. Their qualifications ensure impartial evaluation and uphold the competition's standards.

Beyond its competitive aspect, the competition is an avenue for innovative and sustainable concrete formulations and construction techniques. As a participant, exploring alternative materials and researching various combinations of aggregates and admixtures enhances the performance and sustainability of concrete. By infusing eco-friendly practices into the Concrete Canoe project, the aim is to contribute to environmentally responsible engineering solutions, reduce the project's ecological footprint, and encourage a broader awareness of sustainability in engineering practices. This paper delves into the technical design and 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.

Case Context

An essential aspect of constructing a concrete canoe is the mix design. Concrete canoe construction demands a precise mix design to meet specific structural and performance requirements. It involves 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 using critical factors such as specific gravity, density, and compressive and tensile strength, which 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, 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. Concrete mix design is an art and science that balances components for structural needs, environmental sustainability, and project-specific performance criteria. Figure 1 illustrates the general process of concrete production.

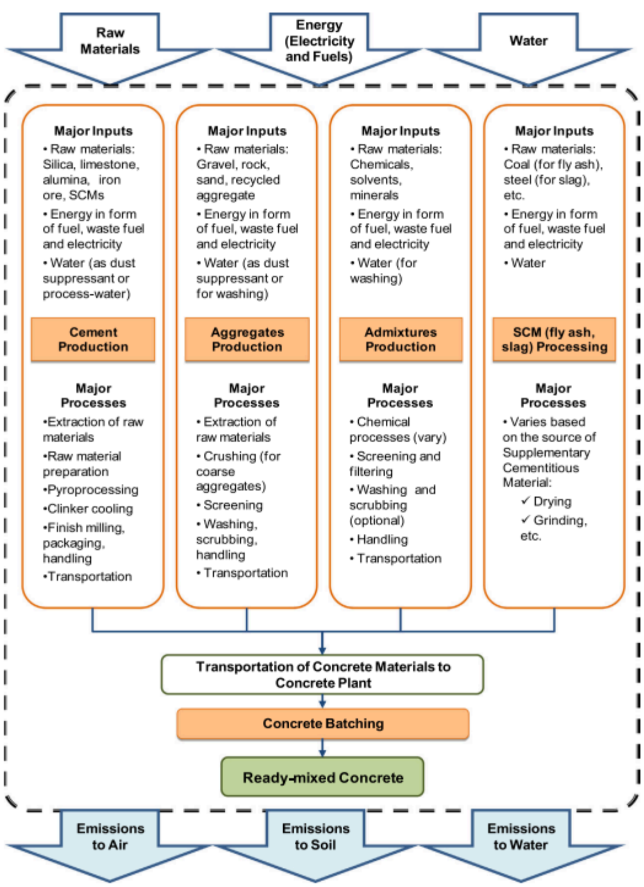

Figure 1. Diagram of the general process of concrete production (Petek Gursel, Masanet, Horvath, & Stadel, 2014)

Despite its immense importance in construction today, concrete is considered unsustainable primarily due to its production's high carbon and water footprint. The most carbon-intensive phase in concrete production is cement manufacturing due to the calcination of limestone and the heating of cement kilns to produce clinkers (Bandera, 2022). The creation of cement is the single largest industrial source of greenhouse gasses, accounting for around 8% of global emissions (Ellis, Badel, Chiang, Park, & Chiang, 2019). To produce more sustainable concrete, initiatives involve adopting alternative binders with lower carbon emissions, incorporating recycled or greener materials, and optimizing mix designs. By embracing these strategies, the construction industry can significantly reduce emissions and create a more eco-friendly environment.

For *'Hoos on the Move*, this year's mix design goal is to create an environmentally sustainable and less carbon-intensive blend that aligns with the Request for Proposals (RFP), a document that outlines the requirements, objectives, and evaluation criteria for the project and its mission. The preliminary mix designs excluded cement due to its significant environmental impact, but after further testing, a mix design that included a 'greener' cement was selected. Inspired by Youngstown State University's 2022-2023 mix design, our team explored 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. It is known for its lower carbon footprint than traditional cement due to the less intense kiln firing requirement and its ability to reabsorb the carbon dioxide it releases through a process called carbonation, making it carbon neutral (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 expanded bead aggregate crafted from 100% recycled glass and a naturally occurring expanded shale in the concrete mix. Using these materials is an eco-conscious approach that aligns with our commitment to sustainability and environmental responsibility. Appendix A presents the design details, and Figure 2 shows a picture of the final product in the water.

Figure 2. Picture of Jason Wong and Chris Herath navigating the slalom course in the *Row-Tunda*

By actively seeking eco-friendly alternatives and reducing dependence on traditional cement, our team aims to substantially contribute 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 *'Hoos On the Move* 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 cooperation 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 more significant. 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, diversity of backgrounds and experiences is not just an asset but a necessity. Despite clinching its seventh national title in 2023, teams like California Polytechnic State University (Cal Poly) reflect a concerning trend. Their team predominantly consisted of civil engineering students, except for 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 crucial for groundbreaking innovation. In engineering, where the stakes are high, and the challenges are multifaceted, the absence of diverse academic backgrounds is not 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 address intricate challenges effectively. 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. They are typically characterized by ambiguity, uncertainty, and the absence of a clear solution. This lens, as applied to 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 symbolic 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 more environmentally and socially 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 document analysis on the project proposals submitted by each team participating in the regional Concrete Canoe competition held at Virginia Tech from March 28th to the 30th before the competition (ASCE Student Symposium, 2023). These proposals offer valuable insights into practical, sustainable mix design strategies. The analysis will shed light on opinions related to sustainability in concrete mix design, trade-offs between environmental concerns and practical feasibility, interdisciplinary collaboration, diversity within teams, and the long-term impacts of sustainable concrete mix design on the construction industry. Following the competition, I will compare these initial proposals with the outcomes and rankings of the competition. This comparative analysis will identify how closely the teams' proposed designs and practices correlated with their actual performance and final standings, highlighting any significant predictors of success or failure evident from the initial proposals.

Coding the responses based on common themes allows for a quantitative understanding of the distribution of opinions and experiences among the participants. I seek insights into how teams prioritize sustainability considerations and incorporate innovative eco-friendly practices into their mix designs. Additionally, the effects of diversity and interdisciplinary collaborations within their teams will be explored to derive a relationship between sustainability and team diversity. By addressing these concerns, we can pave the way for a more sustainable future in construction, with concrete mix design playing a pivotal role in shaping environmentally conscious engineering practices.

Results

The analysis of various schools participating in the regional Virginias Concrete Canoe Competition reveals several commonalities and differences in their approaches to sustainability and innovation. Across all nine teams, there is a notable emphasis on environmental sustainability, with each team utilizing various lightweight, eco-friendly materials as substitutes for Portland Cement. Prevalently used cementitious materials, such as Portland limestone cement, slag cement, hydrated lime, and fly ash, are employed. Moreover, there is widespread utilization of lightweight natural or recycled aggregates, including expanded clay and recycled glass beads, dramatically decreasing the density of the prototypes. Appendix B lists the mix design materials used by each team.

Additionally, most teams prioritize economic sustainability, seeking cost-effective solutions for their prototype, such as reusing past materials. Finally, while some teams focus solely on technical aspects, others integrate social sustainability considerations into their approach, emphasizing interdisciplinary collaboration and diverse perspectives.

Liberty University, Miller School of Albemarle, Old Dominion University, and the University of Virginia Exhibition Team demonstrate similar approaches to sustainability by prioritizing environmental and economic aspects. They employ various lightweight and less carbon-intensive materials in their mix designs. However, they differ in their levels of innovation and social sustainability integration. Fairmont State University and West Virginia University showcase innovative approaches through unconventional curing methods and material usage. In contrast, others like Liberty University and Old Dominion University adhere to more conventional techniques. Fairmont State University constructed a humidity chamber made primarily of PVC pipes to produce consistently reliable prototypes with an innovative yet cost-efficient process. The chamber allows for maintaining optimal moisture during the curing process in an easily replicable and readily available way. As for West Virginia University, the team applied a small amount of recycled ground rubber after intensive research. While having no inherent benefits, it helped to reduce rubber waste from industries.

In contrast, the University of Virginia team uniquely emphasizes social sustainability by highlighting interdisciplinary collaboration and diverse perspectives as crucial factors in its success. It also highlights the club's evolution to an academic program and a dynamic capstone project. Similarly, Virginia Tech and Virginia Military Institute also acknowledge the importance of diversity within their teams, as highlighted in their respective project proposals. They recognize diversity as a valued aspect that contributes to the success of their sustainability initiatives. Figure 3 depicts the conducting of thematic coding analysis to identify recurring themes and patterns in the approaches to sustainability among participating teams.

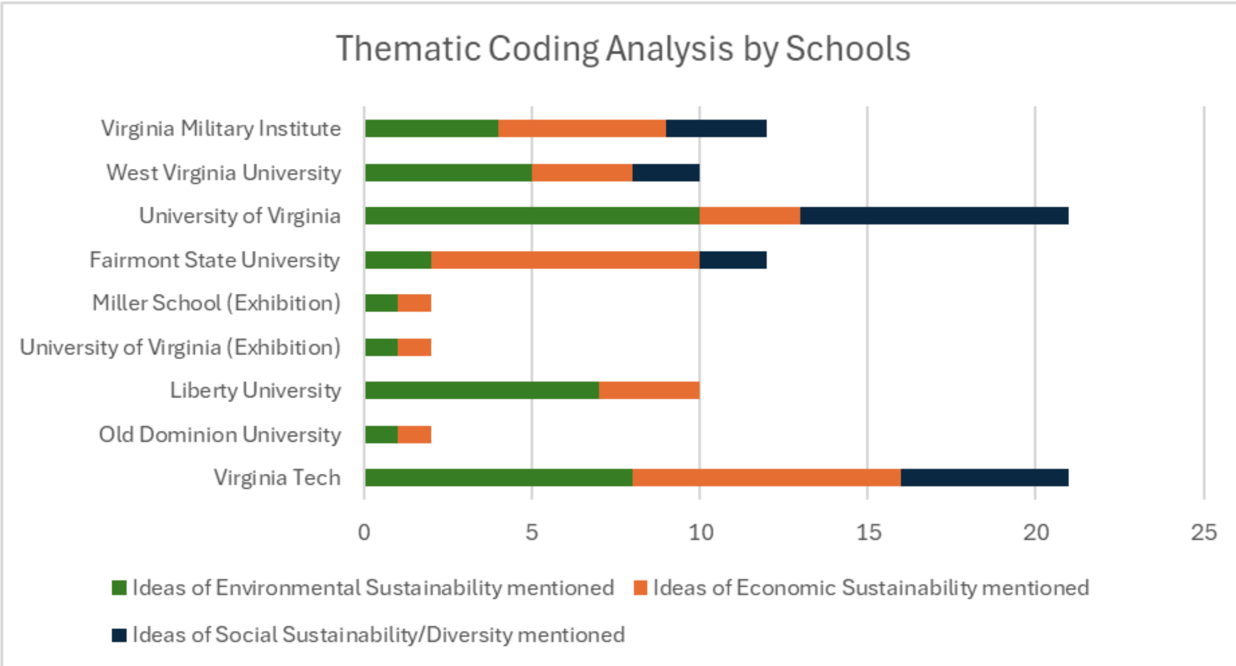

Figure 3. A chart detailing the number of times each school mentioned a pillar of sustainability

Applying Seager's Sustainable Engineering Science framework to the Virginia Concrete Canoe Competition results, we can discern how each team's approach aligns with sustainability and interdisciplinary collaboration principles. The emphasis on environmental sustainability, demonstrated by utilizing lightweight and eco-friendly materials, reflects Seager's call for considering the long-term consequences of engineering solutions. Integrating social sustainability considerations, such as interdisciplinary collaboration and diverse perspectives, echoes Seager's advocacy for harmonious integration of social and technical dimensions in engineering challenges.

Interviews conducted with the Virginia Military Institute team revealed that including members with diverse backgrounds, such as two biology majors and an electrical engineering major, significantly contributed to the team's success in the concrete canoe project. The biology majors brought biological processes and environmental sciences expertise, offering valuable insights into sustainable material selection and ecological considerations. Furthermore, the electrical engineering major provided innovative perspectives on the technical aspects of the project, particularly in developing electronic systems for data collection or monitoring purposes.

Similarly, interviews with the University of Virginia team revealed the benefits of having members with diverse academic backgrounds, including mechanical engineering, economics, pre-medical studies, and computer science. The mechanical engineering major brought expertise in structural analysis and design principles, while the economics major offered insights into cost-benefit analyses and financial management strategies. Furthermore, the pre-medical student's background contributed to a holistic understanding of human health and safety considerations, integral to sustainable engineering practices. Lastly, the computer science major facilitated the integration of digital technologies and computational modeling techniques into the project, enhancing efficiency and accuracy in various aspects of the design and analysis process. Illustrating their collaborative efforts, Figure 4 captures the University of Virginia team in action at Virginia Tech during the competition.

Figure 4. Picture of the University of Virginia 2023-2024 team

Comparative analysis of the findings indicates that the diverse expertise brought by team members enriches interdisciplinary collaboration, broadens problem-solving approaches, and ultimately contributes to the sustainability and innovation of concrete mix designs. Project proposals from schools that explicitly mentioned diversity or addressed the social pillar of sustainability often exhibited a higher level of detail and professionalism. Reports from these schools showcased intricate information, thorough research, and comprehensive analysis, indicating a deeper understanding and commitment to sustainability principles. The study suggests that teams emphasizing diversity and social sustainability contribute to broader problem-solving approaches and demonstrate heightened professionalism and dedication to their projects. Including diverse perspectives and interdisciplinary collaboration fosters a more robust and comprehensive approach to concrete mix design, resulting in more innovative and sustainable solutions.

Table 1 lists the final rankings of the schools and the total points they earned during the competition.

Table 1

Final Summary - Sorted by Rank

Ranking	School Name	Points
1	Virginia Tech	93.9
2	University of Virginia	84.1
3	Fairmont State University	73.8
4	Miller School (Exhibition)	69.8
5	West Virginia University	60.1
6	Liberty University	58.6
7	Old Dominion University	29.1
8	University of Virginia (Exhibition)	28.2
9	Virginia Military Institute	19.5

The final standings of the competition showcased an exciting relationship between teams that explicitly emphasized the social pillar of sustainability and their overall ranking compared to those that did not. Teams like Virginia Tech and the University of Virginia, which highlighted the importance of diversity within their team, demonstrated exceptional performance in the competition compared to those that did not, such as Liberty University, Old Dominion University, and the University of Virginia Exhibition Team. Despite being one of the teams that mentioned diversity in their project proposal, the Virginia Military Institute team experienced critical damage to their prototype during transportation, resulting in its inability to partake in most of the competition. While the final rankings could be influenced by factors beyond team diversity or interdisciplinary collaboration, such as technical expertise, material selection, and construction methodologies, a potential correlation between teams that emphasized the social pillar of sustainability and their performance in the competition is worth noting. This relationship suggests that aspects like diversity within the team contribute to a more well-rounded approach to problem-solving and innovation, which could reflect positively on the competition standings.

After examining the competition's dynamics and outcomes, it becomes evident that there needs to be more emphasis on the social pillar of sustainability, interdisciplinary team compositions, and diversity within many participating teams. This observation suggests a potential fundamental issue with the competition framework, which may lean towards a quantitative assessment of teams' approaches rather than a qualitative evaluation. By prioritizing quantitative metrics like technical expertise and performance metrics, the competition may inadvertently undervalue the qualitative aspects of sustainability and interdisciplinary collaboration, which are increasingly recognized as crucial elements in modern engineering practice. Moreover, this emphasis on quantitative measures could perpetuate a culture of homogeneity and groupthink among participating teams, as schools may approach the competition with similar strategies year after year, potentially stifling innovation and diversity of perspectives.

Discussion

In evaluating Seager's framework within the Virginias Concrete Canoe Competition context, it becomes evident that his Sustainable Engineering Science framework offers valuable insights into sustainability and interdisciplinary collaboration in engineering projects. Advocating for a comprehensive approach that integrates social, environmental, and economic considerations, Seager emphasizes addressing complex challenges holistically. Applying this framework to the competition results enables discernment of how each team's approach aligns with sustainability principles. However, practical constraints limit the framework's effectiveness within the context of competition, as the evaluation criteria do not fully capture the qualitative aspects of sustainability and interdisciplinary collaboration advocated by Seager. Addressing this gap involves revisiting the evaluation criteria to incorporate qualitative assessments of teams' approaches. This change would better align the competition with industry practices and theories, fostering a more comprehensive understanding of engineering challenges and solutions among participants and preparing them for real-world engineering practice where sustainability and interdisciplinary collaboration are increasingly integral.

The findings of this study resonate with broader industry practices and theories regarding sustainability and interdisciplinary collaboration in engineering. The emphasis on environmental sustainability, reflected in lightweight and eco-friendly materials, aligns with industry trends towards greener engineering solutions. Furthermore, integrating social sustainability considerations, such as interdisciplinary collaboration and diverse perspectives, echoes industry calls for a more integral approach to engineering challenges. Acknowledgment of the study's limitations is necessary. The scarcity of available data on team compositions hindered deeper analysis of the influence of interdisciplinary collaboration on competition outcomes.

Future research should expand beyond regional competitions to encompass national-level competitions, providing a more comprehensive dataset for analysis. Efforts should also focus on gathering detailed information on team compositions to understand better the impact of diversity and interdisciplinary collaboration on competition success. Despite these limitations, this research lays the groundwork for understanding the role of interdisciplinary collaboration in engineering competitions and its implications for sustainable engineering practice.

In advancing engineering practice, this study underscores the significance of nurturing interdisciplinary projects and opportunities for students. Encouraging collaboration across diverse academic disciplines equips engineering programs to better prepare students for real-world engineering challenges. Furthermore, integrating interdisciplinary approaches into engineering education enhances problem-solving skills and fosters a more inclusive and innovative mindset among future engineers. Institutions should thus consider expanding interdisciplinary initiatives and offering students diverse experiential learning opportunities to ready them for modern engineering practice's interdisciplinary nature.

This research emphasizes the importance of sustainability principles in engineering competitions and industry practices. The findings align with industry trends toward more sustainable engineering solutions, highlighting the need for interdisciplinary collaboration to drive innovation. Recent developments in engineering, such as advancements in sustainable materials and technologies, underscore the ongoing importance of sustainability and interdisciplinary cooperation in engineering practice.

Conclusion

This study delved into the intricate interplay between sustainability, interdisciplinary collaboration, and concrete mix design, using the Virginias Concrete Canoe Competition as a case study. The findings shed light on the innovative approaches employed by participating teams to prioritize environmental sustainability, integrate social sustainability considerations, and leverage diverse expertise within their ranks. By applying Seager's Sustainable Engineering Science framework, the research highlighted the alignment of team approaches with sustainability principles, emphasizing the importance of considering long-term consequences and fostering interdisciplinary collaboration.

The broader significance of this research lies in its contribution to advancing sustainable engineering practices, particularly in the context of concrete production. By showcasing the tangible benefits of incorporating eco-friendly materials and embracing diverse perspectives, this study provides valuable insights for industry professionals, educators, and policymakers seeking to promote sustainability in engineering projects. Moving forward, these stakeholders should leverage the findings of this research to inform decision-making processes, develop innovative strategies, and implement policies that prioritize sustainability and foster inclusive team environments in concrete production and engineering projects. Furthermore, the emphasis on interdisciplinary collaboration underscores the importance of nurturing diverse talent pools and fostering inclusive team environments to drive innovation and problem-solving in engineering challenges.

For future research, it is imperative to expand beyond regional competitions and encompass national-level events to gather more comprehensive data. Efforts should also focus on enhancing data collection methods to enable a more profound analysis of the impact of diversity and interdisciplinary collaboration on competition outcomes, perhaps through a longitudinal study. Additionally, research initiatives should explore the scalability of sustainable concrete solutions and their broader applicability across various construction projects.

The key takeaway message from this work is the transformative potential of interdisciplinary collaboration and sustainability principles in shaping the future of engineering practice. Engineers can develop innovative solutions that meet society's needs and promote environmental stewardship and social responsibility by prioritizing eco-conscious materials, fostering inclusive team environments, and embracing diverse perspectives. Ultimately, this research underscores the imperative for engineering professionals to embrace sustainability as a guiding principle in driving positive change and creating a more resilient and sustainable built environment for future generations.

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Appendix A

Table 1A. Pour Day – Final Mix Design (Wong, 2023)

Materials	Volume (ft^3)	Weight (lb)	Specific Gravity (SSD)	Density (lb/ft^3)
Water	6.41	400.00	1.00	62.40
Buddy Rhodes PVA15 Fibers	0.01	0.63	1.3	81.12
Portland Limestone Cement	2.08	400.00	3.08	192.19
Hydrated Lime Type S	0.67	100.00	2.40	143.52
Blast Slag (GGFS)	2.84	500.00	2.82	175.97
Saturated 2-4 mm Poraver	3.94	177.56	0.72	45.08
Saturated 0.5-1 mm Poraver	2.63	77.00	0.47	29.32
Riverlite Arcosa Expanded Clay	4.38	348.20	1.28	79.56
Air Content (15%)	4.05			

Total	27.00	2003.39	1.19	74.2

Appendix B

Table B1. Material Usage By Team

School Name	Materials Used in Mix Design
Fairmont State University	❖ Roanoke Portland Limestone Cement ❖ Essroc Slag Cement ❖ Vitro Minerals VCAS Pozzolans ❖ Riverlite Expanded Shale Clay ❖ Poraver expanded glass ❖ CenoStar cenospheres 200-600 ❖ Q-cel hollow microspheres ❖ BASF MicroAir ❖ Plastol Ultra 109 ❖ Visctrol ❖ Sika Fibermesh ❖ Fiberforce Macro Fiber
Liberty University	❖ Quikrete Portland Cement ❖ Chemstar Hydrated Lime ❖ NewCem Slag Cement ❖ Sika Fibermesh ❖ EPS Beads ❖ Poraver expanded glass ❖ Fritz-Pak Standard Delay Set ❖ Fritz-Pak Supercizer PCE
Miller School of Albemarle	❖ Portland Type I/II Cement ❖ Western Miracle Type S Hydrated Masons Lime ❖ Hess Standard Pozz ❖ 3/4 " Anti Crack Fiberglass Concrete Fibers ❖ Akona® Liquid Air Entraining Admixture
Old Dominion University	❖ Quikrete Portland Cement ❖ Sikacrete® - 950 DP ❖ Sefa - Fly Ash ❖ Euclid - Microfibers 150 ❖ Poraver expanded glass ❖ Sika® Stabilizer - 4R ❖ Sika® AEA - 14 ❖ Sika® ViscoCrete® - 2100

University of Virginia	❖ CEMEX Type IL Portland Limestone Cement ❖ Graymont Mortaseal Dolomite Lime ❖ Heidelberg Materials Slag Cement (grade 120) ❖ Buddy Rhodes PVA15 Fibers ❖ Poraver expanded glass ❖ Arcosa Riverlite® Alabama Expanded Clay
University of Virginia Exhibition Team	❖ Lehigh Portland Limestone Cement ❖ Graymont Mortaseal Hydrated Lime ❖ Elkem Micro Silica ❖ Norlite ❖ Concrete Sand
Virginia Military Institute	❖ EcoCem® Plus ❖ Sika Fly Ash ❖ SikaFume® DS ❖ Vitro Minerals VCAS 140 ❖ Stalite Washed MS16 Fines ❖ PVP Industries Expanded Perlite ❖ Poraver expanded glass ❖ 3M Ceramic Microspheres ❖ BON Nylon Concrete Fibers
Virginia Polytechnic Institute and State University	❖ Lehigh White Cement Portland Cement Type 1 ❖ CTS Komponent® ❖ Heidelberg Materials Slag Cement ❖ Sikacrete ® M-100 ❖ Poraver expanded glass ❖ 3M™ K37 Glass Bubbles ❖ Polypropylene Fibers ❖ MasterGlenium® 7500 ❖ MasterAir® AE90 ❖ MasterSet® DELVO
West Virginia University	❖ Portland type 1L ❖ Fly Ash Class F ❖ Norchem Silica Fume ❖ Slag Cement ❖ Poraver expanded glass ❖ K25 Microspheres ❖ Rubber ❖ Hess Pumice ❖ Haydite Fines ❖ Stalite ❖ MasterGlenium® 7500