ASCE Concrete Canoe Competition

(Technical Topic)

Environmental Conservationism and Modern Construction Materials

(STS Topic)

A Thesis Project Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science

University of Virginia ● Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

Ethan Ames

Fall, 2023

Technical Project Team Members: Madison Cannon, Melody Cao, Leon Crawford, Kenneth Reyes, Jason Wong

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.

Signature _______________Ethan Ames________________________

Approved ____ Date__________________________

William Davis, Assistant Professor of STS, Department of Engineering and Society

Approved ____ Date __________________________

Ryan Henry, Department of Civil and Environmental Engineering

I. Introduction

Concrete, as you might suspect, is not a material that is particularly well suited for use as the primary construction material of a canoe. Concrete is rough, cracks easily, behaves poorly in tension, and, most importantly, is heavy. The goal of our team is to create a concrete canoe, a feat which the American Society of Civil Engineers hopes will demonstrate the value of an engineering education by applying a deep understanding of the principles of natural sciences to the real world. Our canoe will be entered into a race hosted by the ASCE, where UVA's team will compete against major technical colleges from across the region. In addition to the race, boats will be evaluated on the basis of their design. This means that teams must take into consideration the environmental, social, and technological impacts of their canoe design, and create a compelling narrative based on their approaches to these issues. Concrete is known to be responsible for a considerable proportion of humanity's annual carbon dioxide emissions, and other construction materials used in the fabrication of the canoe's mold and transportation mechanisms may have a similar, if less significant, environmental impact. Focusing on the social impact of this canoe, especially in regards to what materials are used in its construction, will be critical to performing well in the competition. This also gives the team a platform to deliver a valuable message about the importance of using sustainability in civil engineering.

II. Technical Topic

Canoes entered into this competition will compete in a series of races, including a 200 meter sprint, 400 meter sprint, and a 200 meter slalom. The two sprint races each contain a 180 degree hairpin turn at the halfway point of their course, while the slalom requires that the boat be able to constantly pivot (ASCE, 2023, p. 7). In order to succeed in these competitions, each team will design their boat to maximize speed, maneuverability, tracking, stability, and quality of construction. A number of factors come into play when considering how these properties could be improved. The concrete canoe team will divide into three sub groups to address each of these design elements, those teams being the mix design team, hull design team, and construction team.

Lightweight boats will be faster in the water than heavy ones, meaning teams must synthesize a low density concrete mix to minimize weight. This factor determines how much force is necessary to be applied in order to paddle the canoe. It is difficult to reduce the weight of concrete without simultaneously reducing its strength, creating the first significant engineering challenge the team will face in building the canoe. Concrete primarily consists of a solid aggregate (large chunks of solid material responsible for giving concrete its strength), cementitious material (which acts as a binding agent), and water. Finding a lightweight, highly durable aggregate will reduce the vessel's weight while maintaining its strength. The team also needs to determine how much water to use, as using too much or too little water will damage the strength of the canoe. The principal focus of the mix design team will be to acquire materials, create a "recipe" for the concrete mix, and supervise the pouring of concrete into molds.

It is also crucial that the canoe have a hydrodynamic shape in order to improve its speed. The cross sectional curve of the canoe's hull will determine the flow of water underneath the canoe as it turns, making this element among the most significant for the boat's maneuverability. Tracking is the tendency of a boat to travel in a straight line when being paddled, and is dependent on the cross sectional shape and balance of the canoe. The stability of the canoe can be divided into primary and secondary stability, which describe the tendency of the boat to stay upright and the tendency of a boat to return to an upright position after tipping, respectively.

This property is dependent on the balance of the boat, whether or not there are unwanted air pockets in the concrete, and on the relative flatness or curvature of the bottom of the canoe. Quality of construction may describe whether the canoe begins to crack or sink when it enters the water or in transit to the race site. The hull design team is primarily responsible for determining the shape of the canoe, taking all of these factors into account.

The construction team is responsible for fabricating the molds concrete will be poured over or injected into, the apparatus needed for transporting the boats, and any models used for design testing. The construction team is therefore required to work closely with both the mix and hull design teams. The hull design team creates the designs for the mold, meaning the two groups must constantly keep each other appraised of their progress or any major developments. The mix design team will work closely with construction when it comes time to mix and pour the canoe into the final molds.

Capstone team members are in charge of managing the numerous underclassmen who will serve in different capacities on one or multiple teams, serving as captains. Additionally, paddlers need to be trained by a fitness team, and the theme and presentation of the canoe will be determined by an aesthetics team. Each team will work closely with and communicate with the others in order to address the same problems across multiple fronts and to ensure that all designs and applied methods are up to date. Building off of last year's design will ensure that the concrete canoe designed this year is optimized in each of the aforementioned categories, and allows for this year's team to improve on the weaknesses found in a previous iteration of the design.

III. STS Topic

Civil engineers are responsible for determining which materials are used in the structural framework of a construction project. In most cases, some combination of concrete and steel will be used for a modern development, though other materials may be used according to the specific needs of a given development. While these unique demands are typically caused by environmental conditions, such as soil or climate, they may also be associated with other factors, such as financial or community needs. Civil engineers have a unique position in terms of their ability to shape the impacts of large infrastructure projects. Design engineers, for instance, are capable of significantly reducing the carbon emissions of their developments through material selection, though there are a number of obstacles in doing so. These barriers ensure the continued use of materials which are neither sustainable or environmentally friendly, perpetuating processes which will have negative long term impacts on the community. This provides us with the premise of an important question: in cases where the financial interests of a client and environmental interests of project stakeholders are in conflict, how should an engineer respond? Investigation of this topic will involve an assessment of traditional construction materials, establishment of a framework by which the environmental impacts of building materials may be assessed, and research into strategies and technologies that may best meet the demands of both client and community. By applying the framework of environmental conservationism, engineers may rethink modern construction practices to mitigate the harmful environmental impacts of traditional methods and materials.

Concrete is used as a principle material in virtually every major construction project of the modern age. This is due to its high compressive strength, which allows it to support heavy loads, as well as its natural ability to withstand the elements (Nevill, 2011, p. 952). However, concrete is also notoriously harmful to the environment, being responsible for approximately 8% of anthropogenic carbon dioxide emissions on an annual basis (Lehne, 2018, p. 7). Because of the scale of concrete's negative environmental effects, this will be the primary material focused on in this investigation.

Concrete consists of two primary materials: aggregate and cement. Aggregate is a collection of granular materials, like gravel, which is mainly responsible for determining the concrete's material strength. Cement is a binding agent which, when mixed with water, forms a cohesive solid which holds the coarse aggregate together. Both of these components are essential to the formation of concrete, and have significant detrimental effects on the environment.

Coarse aggregate is typically mined from crushed or broken up rock, and shipped to site for mixing. This process, both in mining and transportation, releases large amounts of carbon dioxide into the atmosphere. There are also concerns regarding how much aggregate can be sourced from a certain location before local ecosystems are affected (McNeil, 2013). Cement also plays a major role in determining the extent of a batch of concrete's environmental impact, with 0.9 lbs of carbon dioxide emitted for every pound of cement manufactured (Portland Cement Association, n.d., p. 2).

In spite of these drawbacks, concrete remains to be an industry standard when it comes to material selection in major construction projects. Concrete is relatively cheap to acquire in bulk, and exhibits an impressive ability to resist compressive force. When paired with internalized rebar, concrete may also perform well under tension, making it a fairly versatile material. Concrete is highly resistant to fire, and can last for long periods of time in the elements without losing its structural integrity; it is also easy to mold and can therefore be used in a wide variety of applications (Nevill, 2011).

In addition to any technical reasons one can identify, many social systems are in place which maintain the status of concrete as a primary construction material. If concrete is mishandled during the construction process, or improperly attended to after construction is complete, material failure may occur, leading to devastating consequences. For this reason, many government regulations have been set in place for concrete based construction projects, which act as quality control measures (Gjorv, 2011). Because concrete is so common, these regulations are fairly straightforward and are therefore easy for engineers and construction workers to comply with. The same cannot be said on remotely the same scale for any alternative building material that may be implemented as a sustainable counterpart to concrete. Construction schedules may face significant delays as plans await approval, and clients may become concerned by potential cost and liability issues stemming from use of alternative construction materials (United States Environmental Protection Agency, 2023).

Civil engineers are therefore faced with heavy pressure to utilize concrete in their designs, especially for larger developments bearing heavier loads. Technical, financial, and social pressures each indicate that concrete is an ideal material for use in major projects, despite the known environmental drawbacks of its usage. This all makes sense on the surface, though it begs the question – who is going to bring about the shift away from concrete towards sustainable materials if not the design engineers whose creations are responsible for the enormous demand for concrete we see today? Do engineers have a greater responsibility for the environmental impact of their creations, or to their clients?

As a philosophy, Environmental Conservationism may be described as the idea that the materials we source from the environment ought to be obtained in a way that ensures their continued availability and maintains ecological balance (Rome, 2003, p. 1). Material should be acquired through sustainable means and without risk of pollution in the environment. Unlike preservationists, who call for human non-interference in nature, the conservationists strike a balance between human needs and what they consider to be an ethical obligation to protect nature (Rome, 2003, p. 1,3). The framework of environmental conservationism is useful for this investigation, as it doesn't fully prohibit engineers from meeting the needs of their client, but it does demand that engineers protect community stakeholders in regard to the environmental impact of their developments.

Assuming that the conservationists are correct, that humanity has both a duty to protect the natural world and the ability to do so while acquiring the materials necessary for society to function, then Civil Engineers are not exempt from their charge. In fact, engineers may have the most power of any discipline to strike a balance between the human and natural elements at play here. The challenge then becomes to develop a material which fills the role of concrete in a structural system, while keeping costs low and minimizing carbon dioxide emissions.

A number of materials and technologies are being developed to reduce the environmental impact of concrete, such as rammed earth. Rammed earth bricks are created from densely packed dirt. Soil is hydrated, compacted, and left to cure until it reaches its design strength. Modern rammed earth is often mixed with trace quantities of cement, which provides it with increased strength and resilience to the elements, such as rainfall. This material, cement stabilized rammed earth (CSRE) shows immense promise as an eco-friendly building material (Kariyawasam, 2016). Rammed earth bricks behave well in compression, meaning they can support heavy loads, but fail under tension, both of which are properties they share with concrete.

Rammed earth bricks are not yet widely used as a construction material due to their diminished strength compared to concrete. They also take more man hours to assemble, and are therefore more expensive to produce than a simple concrete mix (Greenspec, 2020). However, rammed earth is known to have significantly less of an environmental impact than concrete. CSRE is still a developing technology, and stronger rammed earth mixes are constantly being developed. Rammed earth cuts out the carbon dioxide emissions created in mining and crushing aggregate, and doesn't need to be transported long distances due to the ready availability of soil (Ciancio, 2013, p. 4). They are also responsible for less off-gassing of chemical contaminants than concrete, which has immense health benefits for the occupants of buildings built out of rammed earth (Keefe, 2005).

Rammed earth also has a historical precedent, as virtually all buildings from before the modern age were built out of rammed earth in one form or another. Rammed earth is still used in many parts of the world, especially in the developing world, where access to modern construction technology is not reliable (Maniatidis, 2003, p. 10). For this reason, much of the skepticism that an alternative building material might receive from contractors and government regulators would not fall as heavily on a rammed earth structure.

Rammed earth is not able to support the same heavy loads as concrete. This means that it will likely never be used in skyscrapers, dams, or other such buildings. However, it will likely find its place in the construction industry, as it can be used in residences, roads, and retaining walls. This reduction in the use of concrete would not be insignificant for anthropogenic carbon dioxide emissions.

Carbon net zero concrete may be another possible alternative to existing concrete mixes. Carbon net-zero concrete is infamously much more expensive than conventional concrete (Slanger, 2022). However, this cost may be reduced as the technology needed to produce carbon net neutral concrete becomes increasingly widespread. Carbon-net zero concrete maintains the material properties of concrete while being ecologically friendly, and receives significantly less skepticism from regulators and stakeholders.

If engineers behaved as independent actors in creating a building design, integrating these sustainable materials into new designs could happen very easily. However, engineers in the modern age are much more likely to be acting on behalf of a larger firm, representing a paying client. This inhibits their autonomy, limiting their ability to make decisions which may cost the client more money than necessary. Deviation from tried and true construction methods would be virtually impossible if systems, such as the LEED Certification, weren't in place to encourage developers to create sustainable designs.

LEED (Leadership in Environmental and Energy Design) Certifications are awarded to buildings which exhibit exemplary commitment to sustainability in their designs (Kubba, 2009). The US Green Building Council awards points based on a variety of criteria across a site design, and delivers a rating of Certified, Silver, Gold, or Platinum to buildings which qualify. While these awards aren't associated with any direct monetary benefit, it becomes a powerful marketing tool for all parties involved in a project. LEED Certifications are highly sought after, and have been proven to encourage designers to pursue environmental conservationist practices. Additionally, other policies, such as government subsidies for LEED Certified buildings, may further extend the feasibility of ecologically friendly replacements for standard concrete in modern construction projects.

Civil engineers are among the most powerful voices for widespread change in construction materials, given that their technical expertise and proximity to infrastructure projects grant them a unique vantage. Engineers have a responsibility both to the environment and to their client, and have the ability to create innovative designs which meet the needs of both parties. Acting as environmental conservationists may encourage engineers to develop new sustainable technologies for use as construction materials, replacing the materials which are considered to be the modern standard. Engineers' work gives them a role in society that is not purely technical, but also gives them room to impact their community and the environment while meeting the needs of their client.

IV. Conclusion

This project centers on creating an environmentally-friendly design for a concrete canoe. This canoe, which will operate at a high degree of functionality despite the limitations imposed by its material composition, will help others understand the power of applying engineering principles to achieve both a practical and social impact. The final deliverables of this project, which involve testing and presenting the canoe design, will exemplify how engineering can achieve both of these impacts. A successful project would mean that the canoe floats, performs well in races, and is environmentally friendly. All of these features should be depicted clearly for the sake of the judges and general audience. Concrete, the material which composes most of the canoe's mass, is infamously harmful to the environment due to the large quantities of carbon dioxide emissions associated with sourcing and producing aggregate and cementitious material. Environmental Conservationists believe that construction materials should be sourced and used in a sustainable, environmentally-friendly fashion. A number of new construction material technologies are currently being developed in order to satisfy this demand, including rammed earth. This, like many of the principles which are involved in designing a concrete canoe, demonstrates how engineering skills may be used to create positive change for society.

V. References

ASCE, Marshall, J., J., Hilscher, M., & ASCE. (2023). *COMMITTEE ON CONCRETE CANOE COMPETITIONS*. https://www.asce.org/-/media/asce-images-and-files/communities/students-and-younger-members/documents/2024-asce-concrete-canoe-competition-request-for-proposals-rules.pdf

Ciancio, D., & Beckett, C. (2013). *Rammed Earth: An Overview of a Sustainable Construction Material*. Third International Conference on Sustainable Construction Materials and Technologies. http://www.claisse.info/2013%20papers/data/e053.pdf

Fairmont State University. *Fairmont State ASCE Concrete Canoe Team places first at regional competition*. (n.d.). Www.fairmontstate.edu. Retrieved October 8, 2023, from https://www.fairmontstate.edu/news/2023/04/fairmont-state-asce-concrete-canoe-team-places-first-regional-competition.aspx

Gjørv, O. E. (2011). Durability of Concrete Structures. *Arabian Journal for Science and Engineering*, *36*(2), 151–172. https://doi.org/10.1007/s13369-010-0033-5

Greenspec. (2020). *GreenSpec: Environmental Advantages of Rammed Earth Construction*. Www.greenspec.co.uk. https://www.greenspec.co.uk/building-design/rammed-earth/

Kariyawasam, K. K. G. K. D., & Jayasinghe, C. (2016). Cement Stabilized Rammed Earth as a Sustainable Construction Material. *Construction and Building Materials*, *105*, 519–527. https://doi.org/10.1016/j.conbuildmat.2015.12.189

Keefe, L. (2005). *Earth Building*. Google Books. https://books.google.com/books?hl=en&lr=&id=cCGAAgAAQBAJ&oi=fnd&pg=PR1&dq=related%3AQPuiWGX3chYJ%3Ascholar.google.com%2F&ots=j-2iTZwkRc&sig=OObC1Ys6Vjg_34FXXJ_5K7N61RA#v=onepage&q&f=false

Kubba, S. (2009). LEED Practices, Certification, and Accreditation Handbook. In *Google Books*. Butterworth-Heinemann. https://books.google.com/books?hl=en&lr=&id=x_Rnb9uIiQQC&oi=fnd&pg=PP1&dq=leed+certification+&ots=LQ5JOJs7HO&sig=F6dIeQGoLzjb6dvxN0mo55ak21o#v=onepage&q=leed%20certification&f=false

Lehne, J., & Preston, F. (2018). *Chatham House Report Making Concrete Change Innovation in Low-carbon Cement and Concrete*. https://www.chathamhouse.org/sites/default/files/publications/2018-06-13-making-concrete-change-cement-lehne-preston-final.pdf

Maniatidis, V., & Walker, P. (2003, May). A Review of Rammed Earth Construction - University of Bath. https://people.bath.ac.uk/abspw/rammedearth/review.pdf

McNeil, K., & Kang, T. H.-K. (2013, March 29). *Recycled Concrete Aggregates: A Review - International Journal of Concrete Structures and Materials*. SpringerLink. https://link.springer.com/article/10.1007/s40069-013-0032-5

Nevill, A. M. (2011). *Properties of Concrete Nevill, 5th Edition - [PDF document]*. vdocuments.mx. https://vdocuments.mx/properties-of-concrete-nevill-5th-edition.html

Portland Cement Association. (n.d.). *CARBON FOOTPRINT WHAT IS IT? INTEGRATED PAVING SOLUTIONS.* https://www.cement.org/docs/default-source/th-paving-pdfs/sustainability/carbon-foot-print.pdf

Rome, A. *Conservation, Preservation, and Environmental Activism: A Survey of the Historical Literature*. (2003). Retrieved October 27, 2023, from https://archives.iupui.edu/bitstream/handle/2450/664/Conservation.pdf?sequence=1

Slanger, D. (2022, June 27). *Low-Carbon Concrete in the Northeastern United States*. RMI. https://rmi.org/low-carbon-concrete-in-the-northeastern-united-states/#:~:text=In%20a%0recent%20interview%20with

United States Environmental Protection Agency. (2023, January 23). *Comprehensive procurement guidelines: Cement and Concrete*. epa.gov. https://www.epa.gov/smm/comprehensive-procurement-guidelines-cement-and-concrete-specifications