GRAPHENE ENHANCED CONCRETE

SUSTAINABLE BUILDING MATERIAL POLICY AND ADVOCACY

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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Technical Team Members: Andrew LeBoeuf

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

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Cement, the main binding ingredient of concrete, is the most extensively used material in the construction industry. Due to its high structural compressive strength and durability, it is employed in the building of structures, bridges, dams, roadways, tunnels and other physical infrastructure. However, in many urban areas, existing infrastructure is nearing the end of its service life. Furthermore, rapid population growth has necessitated expansive infrastructure development and heightened urban sprawl. As such, many pre-existing structures require renovations or replacement. Though concrete is the most abundant manufactured substance, it is among the most environmentally destructive because the concrete industry is responsible for 8% of global annual carbon dioxide emissions (Dell, 2021). In order to keep up with the growing global demands of concrete, graphene nanoplatelet additives are a viable alternative that could lessen the carbon footprint of concrete. With impressive physical properties, cementitious composites reinforced with graphene nanoplatelets have the potential to surpass traditional concrete's mechanical properties like strength and durability, while requiring reduced quantities to achieve these results (Dimov et al., 2018).

Higher quality, more homogenous solutions of dispersed graphene particles are theorized to improve compressive and flexural strengths of cementitious mixtures. Therefore, during the fall semester, this technical project will research the effect of sonication durations on the nanoparticle dispersion, particle size and surface area. The team will use test results from optical microscopy and UV-vis spectroscopy to determine the optimal time parameter to create cementitious mortars for compression testing in the spring. This technical project is tightly coupled with the STS research, which will focus on the directives from governments and corporations that promote low carbon building initiatives, which may include case studies or advocacy.

This project will be accomplished during the Fall 2021 and Spring 2022 semesters, for a total of 28 weeks, as depicted in Figure 1. The technical portion of the project will be mentored by Osman Ozbulut, in the department of Engineering Systems and Environment. The other team member is Andrew LeBoeuf. The STS portion of the project will be advised by Catherine Baritaud in the department of Engineering and Society and will focus on an ANT and technology transfer framework.

PROJECT: GRAPHENE ENHANCED CONCRETE

Task name	Start date	End date	WEEK 2	WEEK 4	WEEK 6	WEEK 8	WEEK 10	WEEK 12	WEEK 14	WEEK 16	WEEK 18	WEEK 20	WEEK 22	WEEK 24	WEEK 26	WEEK 28
PHASE 1: FALL SEMESTER	**9/6/2021**	**12/6/2021**														
Task 1: Read related journals	9/6/2021	9/20/2021														
Task 2: Sonication outline writeup	10/8/2021	10/15/2021														
Task 3: STS Prospectus	10/5/2021	11/1/2021														
Task 4: Begin experimental procedure	10/15/2021	11/8/2021														
Task 5: Particle size testing	11/1/2021	11/16/2021														
Task 6: Analyze results in report	11/16/2021	12/6/2021														
Task 7: STS Qualifying exam																
PHASE 2: SPRING SEMESTER	**1/19/2022**	**4/30/2022**														
Task 8: Prepare graphene cement mix	2/1/2022	2/20/2022														
Task 9: 7 day mortar testing	2/20/2022	2/28/2022														
Task 10: 28 day mortar testing	2/28/2022	3/15/2022														
Task 11: Technical Report	2/28/2022	4/30/2022														
Task 12: STS Research Paper	2/28/2022	4/30/2022														

Figure 1: Gantt chart for graphene enhanced concrete capstone. Includes technical and STS deliverables spanning over the two 14-week semesters. (Heupel, 2021).

GRAPHENE ENHANCED-CONCRETE EXPERIMENTATION

A concrete mix is composed of cement, water, fine aggregate, coarse aggregate, additives, and admixtures. Traditional concrete mainly relies on Portland cement, a mixture of limestone and clay. To be effectively used as the main hydraulic binder, it is heated in a kiln at 1,500°C. This process is extremely energy intensive and releases large quantities of carbon dioxide into the atmosphere (Zamora-Castro et al., 2021). In order to lessen the carbon footprint of concrete, this technical project seeks to explore the development of graphene-enhanced concrete as an alternative to traditional cement-based concrete. Research findings predict that graphene in ordinary concrete could require less material while maintaining the same building loading specifications, leading to better durability, mechanical strengths, and sustainability (Dimov et al., 2018).

Graphene is an attractive new nanomaterial that was discovered in 2004 and has since been dubbed as a ‘super-material’ due its remarkable physical properties such as mechanical toughness (Cataldi et al., 2018). As represented in Figure 2 below on page 4, graphene nanoplatelets (GNPs) are layers of graphene sheets that can be used as nano reinforcement in cement-based composites (Jiang et al., 2020). Findings confirm that increases in cementitious strengths depend on graphene dosages (Ho et al., 2020). Though requiring less volume, certain weight percentages of GNPs can improve the compressive and flexural strength of cement mixes (Dimov et al., 2018). GNP formulations can also enhance the life span of concrete by reducing water permeability, thus lessening future water absorption and crack propagation (Dimov et al., 2018). Yet, a main barrier to the widespread use of GNPs in cement composites is its poor dispersion in aqueous solutions and agglomeration (Jiang et al., 2020).

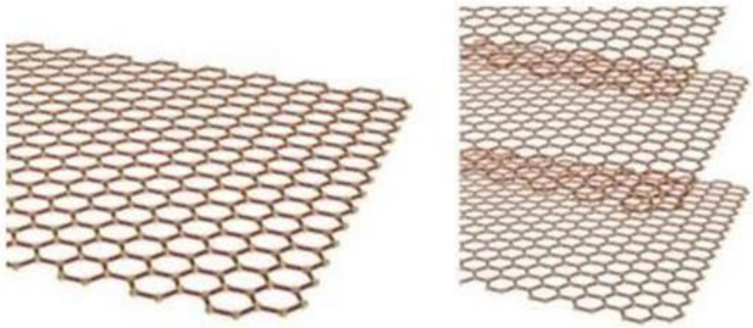

Fig. 2: Schematic representation of graphene (left) and GNP (right). (Adapted by Heupel (2021) from Jiang et al., 2020).

More evenly distributed homogeneous solutions of dispersed graphene particles are theorized to improve the strength of cementitious mixtures. For this reason, the fall semester of the year-long capstone project will investigate ultrasonication, an effective method for the mixing of nanomaterials in solutions. The team will look into the effects of ultrasonication dispersion on graphene particle size/surface area by adjusting time durations. Two different grades of GNPs will be supplied from XG Sciences; one is M- 25 which has an average particle diameter of 25 microns, surface area of 120-150 m2/g, and general thickness of 6-8 nanometers. The other GNP grade is C-300; with an average particle diameter of less than 2 microns, surface area of 300 m2/g, and a smaller general thickness compared to M-25 (XG Sciences, nd).

Research will be carried out using four different ultra-sonication durations, with one control time of zero minutes (hand stirred). All other parameters such as solution volume, amplitude of the probe tip sonication device, GNP concentration ratio, and surfactant to GNP ratio will remain constant. Following experimentation, the team will employ optical microscopy images and UV- vis spectroscopy with the help of MATLAB software to analyze the change in mean particle size, comparing data from before and after mixing.

After sonication duration and its effects on particle size have been examined, during the spring semester, cement samples will be prepared and tested for compressive and flexural strength at 7 and 28 days using the optimal time. A final analysis will include a life-cycle analysis comparison of graphene- reinforced concrete versus conventional concrete. The aforementioned experimentation steps are displayed in Figure 3. The project results will be presented in the form of a conference paper. Available resources include the Baber structure lab and Jesser Hall nanoscale materials characterization facility. These labs house the probe sonicator, UV-vis spectroscopy and optical microscopy equipment that will be necessary to conduct graphene particle size and cement specimen testing.

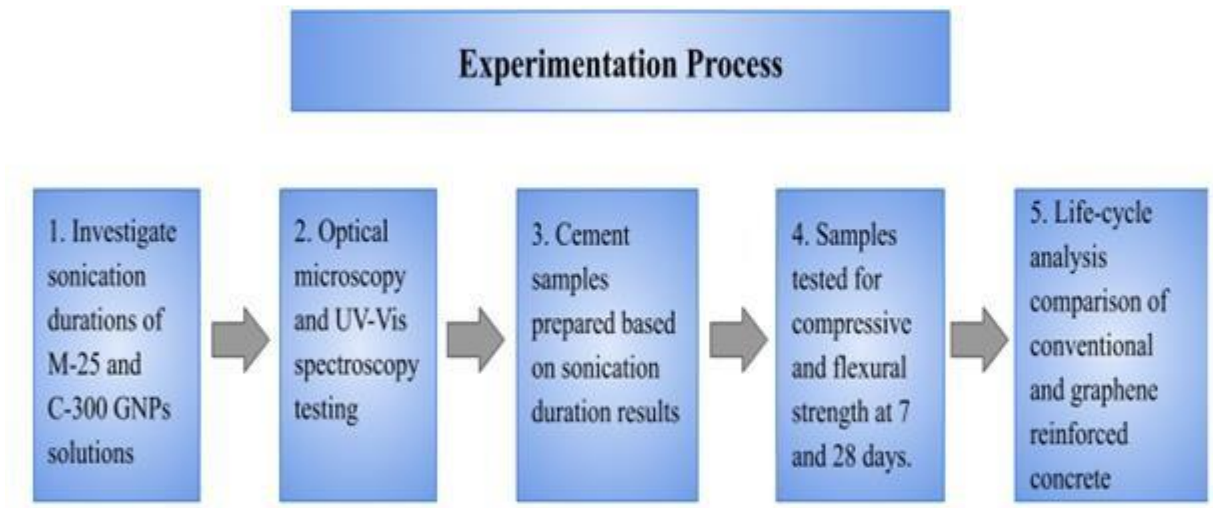

Fig. 3: Necessary steps that will be taken during the experimentation process. (Heupel, 2021).

SUSTAINABLE BUILDING MATERIAL POLICY AND ADVOCACY

The efficient use of cement in concrete, subsequently, concrete in infrastructure developments is necessary to limit the effects of climate change. On a global scale, greenhouse gas emissions have increased an average 5% per year, just through cement production and it is projected to be 6 billion tons by 2025 (Kurad et al., 2017). In 2020 alone, the United States' consumption of cement was nearly 102 million tons, which has been steadily increasing over the last decade (Garside, 2021).

Infrastructure systems are the backbones of the socioeconomic development of a community; therefore, its maintenance and investment are critical (Das et al., 2020). Specifically in the U.S, there is a heightened need for renovation, repair and replacement due to a crisis of degrading infrastructure. The latest report card from the American Society of Civil Engineers (ASCE) evaluated U.S infrastructure as a C minus (Russonello, 2021). ASCE has estimated that existing infrastructure will require an investment of up to 3.5% of US GDP (Das et al, 2020). Though cities and states have made efforts to invest in new infrastructure technology, transformational investment has been lackluster until Biden's $1.5 trillion infrastructure proposal, with the Moving Forward Act (Russonello, 2021). Although this investment by Congress is imperative, the need for rebuilding and renovations will only exacerbate climate change, likely resulting in an increase in carbon dioxide emissions by 200 million tons (Dell 2021). Unless new sustainable measures are taken, the American public cannot rebuild, without greatly adding to the climate change problem.

SUSTAINABLE BUILDING MATERIAL IMPLEMENTATION

In order to negate the carbon dioxide effects of increased construction, we must examine the industry itself. The barriers to adopting green technology is linked to the inner workings of the construction industry, since it is often "blamed for being inefficient, non-sustainable compared to other sectors" (Egmond, 2019, para.1). Particularly in construction, most innovations are incremental due to its multiple actors and disciplines. Thus, construction innovations are considered to be a response to external needs, particularly that of the client (Harty, 2008). Additionally, these innovations are expected to yield immediate results on projects such as reduced costs, increased quality, increased sustainability, better planning, or increase in the structural material's life cycle. Coupled with other limiting factors, pictured in Figure 4, innovations often originate from elsewhere since according to Egmond, 2019, the adoption of innovation solutions in the construction market is often impeded, but may be stimulated by specifics based on:

(1) the local economic and socio-organizational background

(2) the client's particular requirements for sustainable construction

(3) traditional habits in the industry

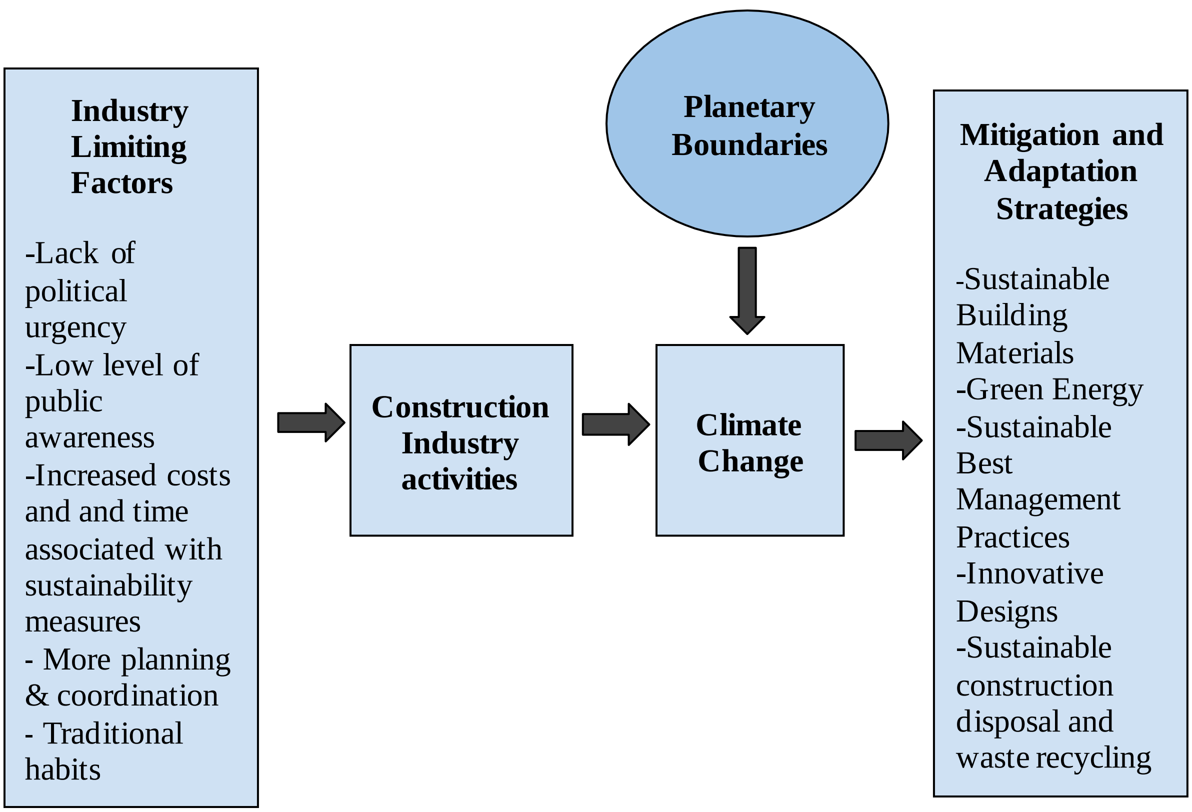

Fig. 4: Visual of construction industry limiting factors towards sustainability and broader green strategies. (Heupel, 2021).

Actor Network Theory (ANT) was developed by Bruno Latour, Michel Callon and John Law, in order to link technology and its processes to social dynamics. According to ANT, a technology's success is dependent on a given mobilization of actors that will either limit or broaden its implementation (Jolivet & Heiskanen, 2010). Moreover, the act of building is a serious innovation to a community, "enabling its proponents to enroll more actors" (Sage et. al, 2019, para.7). Common actors of the industry are the owner, architects, designers, engineers, contractors, subcontractors, material suppliers, research and educational institutes, government, and local communities impacted by the construction. Outlined in Figure 5 on page 9, the technology transfer of graphene-enhanced concrete and other similar sustainable building materials from the engineer are framed within this network to emphasize that their relationships can help or hinder its adaptation. There must be collaboration among various parties in the construction industry to be "restorative and regenerative by intention and design" (Hossain et.al., 2020, para. 1). These actions are necessary from policy-makers, engineers and the scientific community to guide and revamp a broader sustainable construction market (Kylili & Fokaides, 2017).

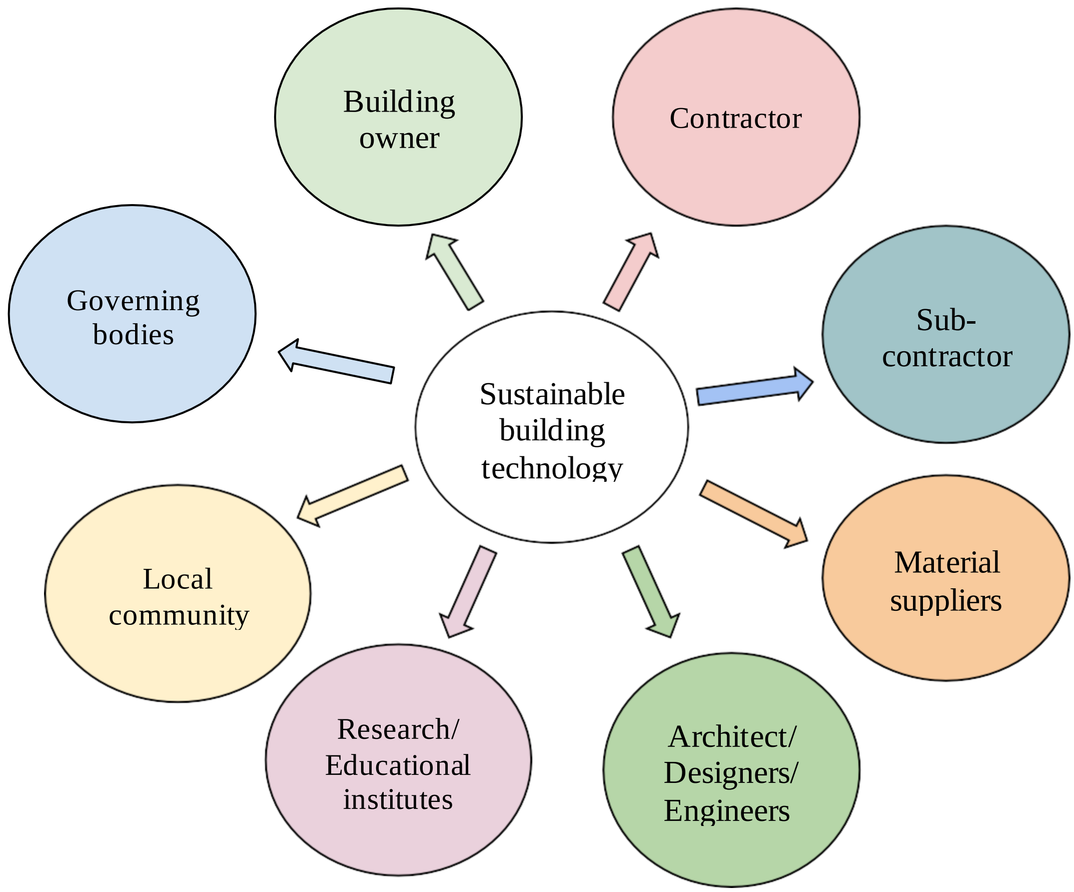

Fig. 5: Representation of various actors in the construction industry, in conjunction with the technology transfer model. This demonstrates the paths of the engineered technology, and that it can be passed to different groups. (Heupel, 2021).

From the ANT and technology transfer framework, the green innovation in construction can be grounded in its contexts and the connections. Hence, this research project will be in the form of a scholarly article outlining the relationship between the solutions to traditional CO2 intensive building materials and the different groups that could adopt this technology or even force its adoption by implementing smart climate standards. On the government side, infrastructure projects are funded through tax revenue, so the public holds a key voice. Therefore, public opinion can point governments and later corporations in the direction of low carbon building initiatives (Dell 2021). An example of state citizens pushing lawmakers for policy has occurred in California, where they have implemented limits on CO2 emissions per unit of building material (Dell 2021). In a similar vein, New York and New Jersey policy makers are considering initiatives that would award credit to public construction contractors that use 'green' concrete advancements in concrete mixes or even zero emission concrete alternatives (Dell 2021). This suggests that sustainable technological solutions depend on urgent policy implementation since without government action and incentives, the goal of reduced greenhouse gas emissions will stagnate.

In contrast, it is argued that the COVID-19 pandemic has sparked climate change proactive action in the private sector. Many in the business industry concur that global business organizations are moving to address climate change risks, even before it is required by government regulations due to climate-related growth opportunities (Marks, 2020). This vision from the clients, presents opportunities for 'green' building technologies in the construction market. Overall, if climate change solutions are perceived as an enterprise to risk management and economic growth, there is greater hope for the incorporation of green concrete in projects and policy (Marks, 2020). However, without the encouragement of governments and policy, the actors, such as building owners, risk-averse engineering companies, and contractors, are unlikely to choose new sustainable concrete options.

PUSHING TOWARD SUSTAINABLE INFRASTRUCTURE

Robust infrastructure is key for a sustainable and resilient development. With the emergence of new sustainable technologies, such as graphene-enhanced concrete, the STS research hopes to uncover the social networks and advocacy that encourage the implementation of 'greener' building materials. In order to maintain infrastructure development in the future, policies which promote sustainable building materials are necessary and industry participation is central to acceptance and success of these technologies. Implementing a new technology has an increased learning curve and actors in the construction industry often favor using materials that they have been accustomed to. In response, governmental agencies would be pivotal in encouraging use of sustainable methods and materials. Overall, for its widespread use in construction sites, efforts by engineers, governments, corporations, communities, and other groups must be made before incorporating graphene-enhanced concrete into the building sector.

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