**Thesis Portfolio**

**3D Printable Rebar Free Concrete Members**
(Technical Report)

**Additive Manufacturing, Supply Chains and Disaster Response**
(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science
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Bachelor of Science, School of Engineering

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## Sociotechnical Synthesis

Additive manufacturing (AM) is a processing technique, by which a part is fabricated in an automated layer-wise manner using input from a digital 3D model. This technology is gaining popularity in a number of fields, like medical and aerospace, where personalized and complex products are especially advantageous (Berman, 2012; Holmström et al., 2010). Another situation that AM is being considered for use in, is disaster response (Gregory et al., 2017; Meisel et al., 2016). The STS portion of my project studied AM's interaction with supply chains and how it relates to a society's ability to quickly and effectively respond to natural disasters. My STS paper examined this topic through the lens of the Actor Network Theory (ANT) and discussed how the introduction of additive manufacturing actors will alter the crisis response network. One specific type of AM, that can be employed in disaster relief, is the 3D printing of concrete to construct shelters for victims of natural disasters (Gregory et al., 2017). Both the STS and technical portions of my project are AM-based and have implications for disaster response, as the technical project has a specific focus on the 3D printing of concrete. As more techniques are being developed, additive manufacturing is increasingly being applied in the structural engineering and architectural worlds, with several companies beginning to create full scale structures using cement-based AM processes (O'Neal, 2016; Starr, 2016). This form of fabrication provides many distinct benefits over traditional cast-in-place concrete constructions, such as the elimination of formwork, the improvement of construction safety via automation, and the allowance for higher geometrical freedom. However, despite these notable benefits, there are still several challenges that complicate the 3D printing of full-scale structures; one such challenge is reinforcement. Steel rebar is traditionally used as reinforcement; however, rebar is not easily incorporated into layer-wise additive manufacturing methods. My Capstone project addresses the technical problem of reinforcement in cement-based AM by examining the mechanical properties of a fiber-reinforced 3D printable concrete mixture and comparing them to traditional cast-in-place specimens. The goal of this project was to design, print and mechanically test a rebar-free beam that has significant flexural strength.

My technical project studied the rheological, printing and mechanical properties of AM fiber reinforced beams. We investigated the flexural properties of beams printed with cementitious composites containing 1 vol% of Polyvinyl Alcohol (PVA) fibers in two different tool paths. Then, the results were compared with two sets of traditionally cast specimens containing no fibers and 1 vol% PVA fibers. The addition of fibers to traditionally cast specimens increased the maximum load the beams were able to support before failure. This confirmed the validity of using fibers as a reinforcement method. Furthermore, we found that the maximum loads carried by the additively manufactured self-reinforced specimens with an optimal tool path were roughly the same as those carried by the traditionally cast specimens with fibers. Through this study, we were able to produce 3D printed self-reinforcing cementitious composites, while showing that the AM process didn't negatively affect the final bending strength.

My STS paper leveraged prior studies to examine disaster relief in terms of ANT and found significant benefits to employing AM technologies in this network, including flexibility of design, onsite manufacturing and quick changes in production. The implementation of AM within the disaster relief network has clear effects on the available supplies, infrastructure, affected community and shipped supplies. However, there still exist challenges, like getting a fully powered machine onto the site, maintaining the supply of feed material and providing skilled operators. In order to be implemented and function properly, AM will need support from the humanitarian aid groups, like money and trained personnel. It is important to consider how the social and technical actors interact to ensure that the technology is being used to its full potential. The information gained in the STS portion will hopefully provide a first step in helping current actors, such as companies, communities and governments, understand the implications of deploying AM in their disaster response plans. During the course of this project, I have learned a great deal about the process of creating concrete and I came away with a better appreciation of some of the challenges facing the concrete industry today. Furthermore, I have been introduced to the complex processes used to respond to natural disasters. It is a unique situation where technology can be directly used to help a community recover from a tragedy and regain their lives.

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