Rebar Free 3D Printed Concrete
(Technical Paper)
Ethics of 3D Printed Concrete
(STS Paper)
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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

3D printing has emerged in all areas of manufacturing as a revolutionary prototyping technology that is just beginning to be used for full production parts. By reducing costs associated with tooling and reducing the time it takes to transfer a design into a finished product, it is an attractive option for many applications but hindered by material limitations and some limitations on manufacturability. In construction, several technical limitations go away and make 3D printed construction a very attractive option that can dramatically reduce costs and lead times on projects. However, other technical problems inherent to concrete itself and imposed by limitations of building design complicate 3D printing being adopted overnight for construction.

In parallel with technical challenges, ethical challenges are also associated with implementing this technology, as construction employs not only designers and managers, but also unskilled manual laborers, skilled laborers, and suppliers of various materials and components. Such a large shift in industry would dramatically disrupt existing labor markets and if done improperly could lead to significant unemployment of individuals without a place in the new construction industry and perhaps any industry.

This thesis seeks to understand both the technical problems and ethical problems associated with this new technology and from that give some idea of how construction in the next decade, or even decades to come, might take place without significantly endangering people’s physical safety or financial well-being.

Rebar Free 3D Printed Concrete

While a widely used structural material, concrete's main weakness is tensile loading. In nearly all structural applications, rebar or prestressing cables must be used to increase the tensile capacity of concrete for it to be used as a structural material and cross sections are designed in order to place more material on the tensile side of the concrete to bear tensile load. In recent years, engineered cementitious composites (ECCs) have been developed with varying reinforcement methods to increase concrete's tensile capacity and ductility and thereby increase moment capacity of beams and bearing capacity of columns, amongst other uses (Schutter, et al, 2018, p. 4). As 3D Printing emerges, the logistics of adding rebar reinforcement make the use of ECC attractive, but current design standards are not sufficient without rebar reinforcement. As a result, this project seeks to develop both a novel ECC mixture that is printable and of higher tensile capacity and optimized beam designs that mitigate tensile loading so as to negate the need for rebar while remaining printable.

In material development, this study seeks to develop our own mixture using polymer fibers, appropriate plasticizers, and mixing techniques to produce concrete capable of being both high strength and printable using existing 3D printers at UVA. Studies occurring here build on existing literature regarding current ECC design but are seeking to optimize printability. Current mixture designs successfully increase tensile capacity but have issues successfully extruding through printer nozzles and adhering together with lower layers of printed concrete. Development is currently adding common elements added to concrete mixtures such as fly ash to improve this mixture, while balancing the addition of composite fibers to retain the added tensile strength.

In design, this project seeks to take advantage of the complex shapes 3D printing can produce. Beams in use in existing structures generally have uniform cross sections throughout their spans. Standard methods of analysis and methods of construction make this the best practice for conventional construction, but 3D printing allows beams to be optimized beyond these simplifications (Hossain, et al, 2020, p. 3). Using small scale concrete beams from other tests as a guideline, section analysis, finite element modeling, and topology optimization are utilized to design concrete beams that reduce tensile stresses in their bottom faces and are devoid of unnecessary weight in areas where stresses are not concentrated. Unlike previous research, this seeks to do so in parallel with studies of 3D printability of the design. Artifacts of the 3D printing process, such as layering, make this necessary, and material properties may vary from those expected for beams cast from the same material.Thus, considering the printing process is necessary to avoid dramatic differences in capacities of designs in finalized tests.

As such, the two sections of the project will combine toward the end to produce a printed concrete beam that should perform similarly to an existing rebar reinforced beam of similar size.

STS Prospectus

Introduction

While 3D printing is a revolutionary technology in construction , its potential to disrupt the labor market is large. Initial data indicates that "...if construction companies can replace just 25% of their projects with 3D-printed structures, they can reduce labor demand by 70% and costs by 90%. (Folk, 2020, p. 1)." While this kind of benefit would be impossible to ignore for developers seeking to reduce costs associated with new construction and contractors seeking to improve the small margins their companies often deal in, these benefits come at the price of economic well-being as well as end user safety.

While progress within industry is unavoidable, the transition can be smoothed. New needs within construction of concrete printers on site, for example, might arise that allow workers to still play a role, as might installation of building components that would not be automated. While this is temporary, this would serve as a buffer to extreme shifts in industry employment, in addition to any construction projects that are not feasible with 3D printing. Not only will these other building components require labor, but other needs might arise for maintenance and construction of concrete 3D printers, as well as in-situ inspection or uses currently unforeseen.

3D printed concrete structures have significantly more variables at play than conventional concrete construction. Building codes have not been updated to reflect this and only in places like Dubai where 3D printing is a priority have full scale structures been built (Ramirez, 2020, p. 2). Rigorous definition of codes as required in the US and factors of safety will be the largest hindrance to large scale printed structures in the US and it may prove impossible for certain cases to be fully replaced with 3D printing. In addition, while printing has potential to revolutionize all construction, cost benefits may mostly be seen in commercial buildings where concrete and steel are common, and areas such as homes may be left to conventional means. While these issues may be solved, It remains possible for workers to not be fully removed from industry.

Research Questions

Based on the overview presented above, the following research questions are posed:

- *How does 3D Printed Construction Impact Current Job markets?*
- *How might displaced workers be utilized in this new industry?*
- *Does safety hinder printed construction from fully upending industry?*
- *Which construction areas might printing be best utilized?*

Literature Review

In certain parts of the word, construction laborers are in short supply, thus 3D Printing is welcomed. As such, "3D printing might not be favorable for the countries where construction is one of the main workforces and labor is less expensive." Thus, both demand and opinions of 3D printing are dependent on existing labor markets (Hossain, et al, 2020, p. 2). Moreover, the stakeholders responsible for these markets evolve rapidly as monied individuals become more attracted to the technology.Though dependent on the market, the cost structure of printing is evolving to make printing attractive. Reductions in labor costs in certain areas indicate extreme cost decreases (Schutter,et al, 2018, p. 2).

In Dubai, where it is a goal to produce 25% of buildings with this technology by 2030, construction is generally used on large luxury projects. Projections from Dubai's government indicate tremendous cost savings and labor reductions by using this technology. Reduction as dramatic as these have potential to upend labor markets and fr=urther the divide between classes in places like this (Folk, 2020, p. 1). While motivations for use in Dubai, 3D printing has the potential to fulfill the need for affordable housing(Ramirez, 2020, p.1). This presents an interesting interplay as people's financial wellbeing is ignored to reduce building costs yet "affordable" housing where these workers might live is being produced.

An additional benefit to 3D printed construction is ease of translation from design to construction. Translation from designer to laborer is traditionally done with 2D representations on paper. Recently, as 3D printing has emerged, printed scale models, in addition to digital models are being used to reduce the complications associated with communication ((Dadi, Goodrum, Taylor, & Maloney, 2014,p. 3). In the Russian market, " calculation and logistics was automated almost 100%. At the same time, specifically when erecting buildings on Russian construction sites, up to 70% of the total labor volume is manual." As expected by figures in Dubai, labor intensity can be decreased and profitability increased by automating the production of buildings(Prokhorov,2018,p. 3). Moreover, this is coupled with potential reductions in construction time(Soto, et al, 2018, p. 3) . These factors in combination may result in alteration of the management structure behind managing and executing projects and create a series of benefits that are difficult to ignore when starting a large construction project.

Stakeholders within the current construction industry are broad in number, as large projects may involve dozens of companies directly followed by their specialized subcontractors. Further, studies of in site integration and early implementation of 3D printing indicate many non obvious stakeholders emerge to complicate the already broad field (Kenji, 2020, p. 7). Analysis of this field requires that the printer be considered as an acto, treated equally as important as the people who use it (Latour, 2005, p. 1). In addition, hybrid stakeholders may be necessary ushc as "cobots," a system where automation and human labor work in tandem to complete tasks (Rosen, et al, 2020, p. 5) . Additionally, to understand just how grave a threat 3D printing may pose, risk society theory may prove useful (Rosen, et al,2020, p. 6).

STS Framework and Method

From early studies of several different STS frameworks, Latour's actor Network Theory proved most useful for understanding the effects of 3D printing on construction. Like others, Latour's theory considers several actors working in play with one another in a complex way that often makes sense to diagram. But unlike others, focuses not only on the human actors in the system but also on the non human actor, in this case the 3D Printer(Latour,2005, p. 1). Because this general type of tool is preferred by designers and corporate entities, but has strong potential opposition from laborers, not considering as if it were an actor ignores how vital it is. Additionally, risk society theory proves useful to consider the interplay between these laborers and the printer, for the socioeconomic impacts associated with reductions in the construction labor market are potentially very large.

Methods for Data collection:

Steps

1. Reach out to existing industry connections with a Google form asking the following
    a. General feelings toward 3D printed construction in multiple choice
        i. Room for elaboration will be needed
    b. Any contacts they believe will be useful

    c. If they would like to set up an in person discussion
2. Set up 10-15 minute interviews via video chat or send over lists of questions to supplement this.
3. Repeat the process as needed.

This should begin with several individuals in each stakeholder group, and lead naturally into other stakeholders who might have otherwise been ignored. LinkedIn will be a good resource here, especially with vocal members of the 3D printed construction community.

The Google form should provide quantitative data that will be useful later, while the interview section should provide data that is not otherwise captured in those forms and might inform new questions for subsequent, alternate paths, or allow opinions not articulated in the form to be more clearly articulated.

The data generated through the above methods is intended to be analyzed with the Actor Network Theory in Mind, though this proves difficult with an actor, the printer, who cannot be interviewed. While new classifications may arise through individuals pointed to by the early round of interviews, generally data can be separated to understand the general opinions of each stakeholder group. From that, quantified data can be shown of general opinions on each matter within a stakeholder and then globally. For example, if the form asks what an individual's general feelings are, data may suggest that 75% of designers feel optimistic, while 75% of laborers feel uneasy. Breaking out information in this way will allow pain points that would not otherwise be captured in global data to be pinpointed. This insight can then be used to spark relevant discussions amongst stakeholders or to indicate that perhaps formal plans or regulations may be needed to see a peaceful proceeding forward.

One bias apparent in this method is that laborers in industry are less likely to be on LinkedIn where early interviewees are to be found or in their professional circles. Thus, perhaps the most vital opinions may be the most difficult to retrieve. Pursuant to this, I intend to ask opinions of laborers I work directly with in related industry, as well as construction laborers I have existing personal connections with to complete these forms and will intend to prioritize detailed interviews with them.

Timeline

1. Google form-1.5 months
2. Video Interviews 1 month
    a. Note: this can occur concurrently with Google forms as needed
3. Data Analysis-2 weeks
    a. Note this is intended to occur concurrently with forms and interviews, but additional analysis will require additional time.
4. Synthesis and Writing- 3 weeks
    a. Early finish here is intended to allow additional time for data collection and analysis as needed
    b. This also allows additional time for comments and changes as needed.

Conclusion

While 3D printing has potential to allow dramatic reductions in cost of buildings and to improve their design, it also poses a significant threat to the established order of the construction industry. The introduction of 3D printing to this industry further complicates an existing, complex network of actors who will need to be analyzed thoroughly in order to effectively understand how best to proceed forward. This requires collection and analysis of data as well as the actor network theory to understand the printers role, and additionally risk society theory. These methods are the only way to fully understand this complex and evolving landscape. With stakeholder opinions quantified into categories, it should be possible to analyze the interplay between stakeholders in this system through actor network theory, with the printer as the central actor, and to consider societal impact on workers, their families, and associated groups that are currently unforeseen.

In the end, the study should shed light onto this issue and may point to specific directions that any sorts of policies or legislation might take. While no formalized recommendations will be made, there should be insight that would be useful to consider as monied and influential stakeholders begin to attempt use of this new technology. In the US especially, policies may be necessary and could be informed by subsequent, similar studies. This may emerge at corporate level, where corporations wish to show their workers they are considering their future, or may result in political and legal upheaval if done improperly.

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