The Effects of 3D printed Construction on the Labor Market

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Dillon Melerine
Spring, 2021

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 _____ Date _____
Dillon Melerine

Approved _____ Date _____
Sharon Ku, Department of Engineering and Society

Introduction

Construction employs people the world from executives and engineers to laborers. While 3D printing has potential to simplify the design process, it also has potential to upend labor markets by reducing the need for workers to lay rebar, set up concrete formwork, or pour concrete. Given how large a sector of employment construction is, this threat could be large enough to cause mass layoffs, and may soon become large enough a threat it attracts political attention. This threat is especially relevant to immigrant laborers, who are vital to the construction industry across the world and in places like Malaysia may make up 70% or more of the labor in that market (Hossain, 2020 p. 5). With such workers being under political scrutiny in certain areas, reductions in their need could upend the roots created in new countries and harm the wellbeing of families they support.

Analysis of this issue first attempted to identify all the relevant stakeholders within the industry and their opinions on what might improve the transmission of design, 3D printing's greatest asset, as well as how workers might sit within the modified industry printing could create. These opinions were then characterized and an STS analysis done using both actor network theory and mediation theory.

Using this basis, 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?*
- *Which construction areas might printing be best utilized?*

Literature Review

While aspects of the construction industry are common knowledge, reading was done into the various aspects of the industry and 3D printing's effect on it, in order to provide informed discussion on the issues. This was especially relevant to provide needed insights from other parts of the world, where labor markets and acceptance of new technologies differ from the US. Moreover, information on specific frameworks was necessary in order for them to more directly be applied to the 3D printed construction industry.

In certain areas, construction laborers are in short supply and 3D Printing is welcomed. According to Hossain, et al (2020), "3D printing might not be favorable for the countries where construction is one of the main workforces and labor is less expensive"(p.2) Thus, both demand and opinions of 3D printing are dependent on existing labor markets. 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 indicates reductions in labor costs (Schutter,et al, 2018, p. 2).

Dubai has a goal to produce 25% of its mostly luxury buildings with this technology by 2030. Projections from their government indicate tremendous cost savings and labor reductions by using this, which have potential to upend labor markets and further the divide between classes (Folk, 2020, p. 1). While Dubai's motivations are commercial, 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 could be 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 drawings. Recently, printed scale models in addition to digital models are being used to reduce the complications associated with communication (Dadi, Goodrum, Taylor, & Maloney, 2014p. 3). In Russia according to Prokhorov (2018) , " 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" (p.3) As expected by figures in Dubai, labor intensity can be decreased and profitability increased by automating building production. Moreover, this is coupled with potential reductions in construction time(Soto, et al, 2018, p. 3) . These factors in combination may be an attractive option for future large building projects.

Stakeholders in the industry are broad in number, as large projects may involve dozens of companies directly and indirectly. 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 actor, treated equally as important as the people who use it (Latour, 2005, p. 1). In addition, hybrid stakeholders may be necessary such 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).

When analyzing implications of a technology, it is easy to consider the technology only as an object and leave it directly out of analysis. Mediation theory reverses this and recognizes that technology helps to shape human world relations in use. In much the same way that actor network theory treats technologies as actors, mediation theory considers technologies mediators

of human-world relations rather than as objects used by actors (Verbeek, 2020, p. 1). This form of analysis is necessary in such a complex technology as 3D Printed Construction due to the number of stakeholders. Leaving out the effects the technology has on people would ignore valuable parts of the interaction and lead to an incomplete analysis.

STS Framework and Research Method

Through review of various STS Frameworks, 2 theories emerged as best to analyze this market. Actor Network Theory proves useful as the printer becomes an actor rather than a tool. This complicates analysis, as the printer cannot be interviewed. Mediation theory also proves useful, as in the creation or design of this new technology, not only is the system designed but also the people around that system and their interactions with it are designed. While this analysis seems somewhat far-fetched, people's behaviors will indeed be affected and the behavior designed by the technology.

Using actor network theory, the abstract idea of the 3D Printer as a tool serves as the single nonhuman actor in this network, with several human actors working in tandem. These mimic the general stakeholders in construction and can be summarized as follows in order of increasing influence: construction laborers, subcontractors, foremen, construction managers, 3D printer manufacturers, engineers, architects, corporate general contractors, developers, and end building users. All human actors in this network have their own financial security as a motivation. The 3D printer manufacturer's well being is directly contingent on the sales of these printers. As such, they recruit general contractors and developers into their network by presenting significantly reduced construction costs as an incentive. The developer is incentivized to recruit end building users, as they will see these cost benefits as well and increase profits on their end. General contractors will be incentivized to recruit their engineers and architects to

evaluate the feasibility of this system and see the improved design and schedule flow it allows. Following this, the developer is inclined to bring in subcontractors, foremen , and workers to create this network and the end building.

Prior analogies have suggested that items are only dangerous in the hand of an actor. A firearm, for instance, becomes dangerous in the hands of a “gunner” but would be a tool in the hands of a hunter. In much the same way, a 3D printer could become a weapon in the hand of the construction contractor. In this sense, it displaces the construction laborer who may not have other skills with which to earn a living, affecting that person’s ability to provide for a family and prosper . The social process of interessment can occur here, as 3D printing presents opportunities for increased success for many stakeholders. Estimates referenced by Folk (2020) indicate 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%”(p. 1). Early adopters of this technology are more likely to be selected in contracts, which might show subcontractors and employers of this contractor great successes. However, this ignores the reductions in labor required throughout the process. As such, the construction workers are coaxed into believing their interests are at heart as they work in tandem with 3D printers. This strengthens their association and supports the network, until workers become unnecessary and are phased out.

Because the integration of 3D printing into the construction industry is not yet complete, it is only possible to observe current developments and speculate on how the network will affect construction of technology and society. At its current state, 3D printing as a general industry has bled into all areas of manufacturing and allowed design techniques that would not otherwise be

possible to be manufactured. However, in most industries, 3D printing the final product is not the cheapest method. Construction, however, allows this to occur and is likely to lead to the translations discussed above. This is partly driven by monied interests like investors seeing 3D printing as a revolutionary cost saving technology, spurning further development. Construction of society as a result of this remains to be seen, but may have grave consequences. For if the integration of workers is handled poorly, huge social upheaval in industry might occur.

Because of the interplay between 3D printers and humans involved in construction, where each shapes the other, Latour's Actor Network Theory proves invaluable to understand the development of the technology itself and society as a result of this technology. The method of analyzing translation discussed above, for example, allows an understanding of why and how each actor is motivated to act and how that might have a ripple effect on the development of the technology itself, and more importantly how the technology/ tool itself affects the network of other actors. Without considering this nonhuman actor, some of this understanding is lost.

Using mediation theory, design of not only the technology, but also the humans who use it is considered. For, the relations that are created by the technology with its users result in the experiences and practices that are the subject of analysis(Verbeek, 2015, p. 28). 3D printing in general, for example, can easily be shown to have done this starting around 2010. When 3D printers became more commercially available, an entire "maker" culture grew, using not only commercial 3D printers, but also industrial machinery. In much the same way, a new culture is likely to emerge as 3D printers make way into the construction industry and additional automation technologies. In both cases, 3D printing affects individuals by showing them the possibilities computers combined with basic technologies can create, spawning further development.

In general, construction companies tend to have long legacies, but this rapid introduction of technology is likely to affect the perceptions of designers and engineers. In the aerospace industry, for example additive manufacturing has allowed more complex shapes to be manufactured, resulting in greater use of optimized geometries. A similar perception change may allow architects and structural engineers to create new structures that could not be created otherwise. In this way, the designers are affected by the technology and it may see more widespread use. A similar embracing of automation may also drive more complicated design of other building subsystems possible with automation. Thus, mediation theory, in addition to actor network theory used previously, makes sense to use in analysis of 3D printed construction technologies.

For application of Mediation Theory, the type of relation, the point of application, and type of influence must be quantified for various relationships. In this case, an embodied relation seems most applicable, as a unity forms between the designer and the printer(Verbeek, 2015, p. 29). This is then directed to the world of construction to be built, potentially having negative effects on the wellbeing of actors rendered obsolete.. Determining the point of contact is more difficult, as one's interaction with the technology depends on their role. For the designer, the relationship is best represented as "Behind the back" as the printer begins to influence design and the designer's experiences. For the worker controlling the machine, however, "to the hand" makes more sense as they are adapting to this new technology and physically using or operating it. The type of influence is more clear, as printers are not hidden, therefore they are not seductive forces. They can be considered coercive, as having this technology means it will be used, if not because of its convenience then because a company has paid for it and wants to see results from it. That being said, the interaction can also be considered decisive, as the convenience of the

printer, more so than the financial expense, may coerce the designer to gravitate towards designs that require it over the more conventional(Verbeek, 2015, p.30).

The analysis shows that design using 3D printing requires responsibility, more so than prior systems . The convenience provided by technology may slowly lead to a preference for this technology that would otherwise not occur. Thus, it is important that the designer remains cognizant of these technologies' influence as he uses it.. This is especially relevant given that this influence can be hidden and coercive.

To better understand this, participants in a survey were asked the list of questions shown in Figure 1. These were sent to individuals in construction and aerospace industries at various levels, as well as other high tech industries. Questions attempted to gauge an individual's understanding of the technology as well as their thoughts on the future it held in construction and how laborers might be affected.Several questions were designed to provide quantitative results that could be compared. Others provided information that could indicate more general trends and thoughts for discussion. This was further supplemented by direct conversations with individuals who were interested in further elaborating.

Interview Type:	Google Form	Answer Type
Question NO:	Content:	
1	What is your level of knoweldge of 3D printing? 1 being none, 10 being an expert	Rate 1-10
2	How large of a role do you expect 3D printing to play in large scale production in 15 years?	Multiple Choice
3	How effective do you find current methods of transfering information from designers to manufacturers and workers?	Rate 1-10
4	Elaborate on your answer above. Do you see 3D printing as improving this process	Writen
5	What role do you see laborers playing in production as automation increases? 1 being none and 10 being vital components	Rate 1-10
6	Elaborate on your answer above. Explain where you see laborers functioning in this new manufacturing/ building area.	Writen
7	Please list any colleagues of yours with email addresses (not just in similar roles) who you believe might be interested in participating in this survey.	Written
8	Would you like to participate in a lengthier phone call to discuss your thoughts oin these topics?	Y/N

Figure 1: Survey Questions Asked of All Participants

Data Analysis

In general, participants' answers to related questions bled through one another such that it became difficult to distinguish the two. This spoke to the interrelatedness of topics and questions, but complicated more quantitative analysis that would allow greater statistical analysis. Future efforts might attempt to eliminate this by breaking things up further or by adding more quantitative questions. However, metrics from the questions designed to be quantitative were able to be captured and are shown in Fig 2.

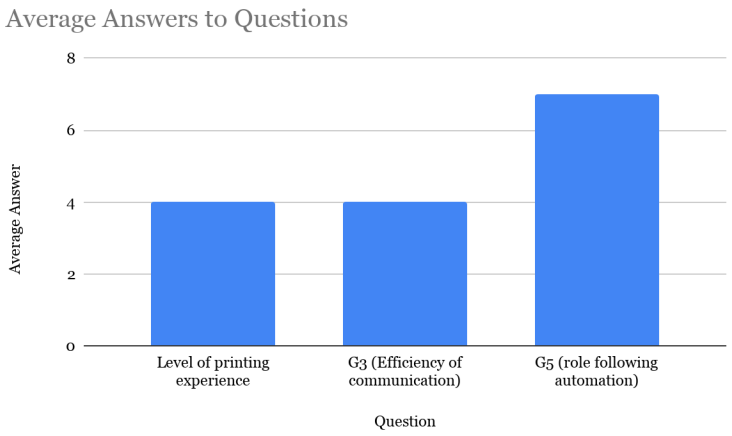

Fig 2: Average Responses to Numeric Questions

In general, a balanced knowledge of 3D printing was found amongst interviewees. Thus there should be less technical bias in other results. Efficiency of communication was shown as low, indicating the need for change discussed earlier. In addition, the optimism seen in labor still maintaining its place is much higher than expected. Perhaps this is indicative of some bias or need to increase the number of participants. Regardless, the data remains valid as a tool for

analysis of 3D printing's effects on construction. The most useful information was in the elaborated answers that informed the discussion, like that shown in Fig. .

Participant Observation	Designer(RP)	9	"In my first job, I watched a huge shift away from 2D pdf drawings to 3D Pdfs as we communicated with suppliers/. It meant that we operated much more efficiently as a company, but there were hurdles we had to jum through to allow everyone to understand and ajdjust to that. WHen I switched companies I went back to the old methods and have started to see more closely how that trnsition worked. So while 3D is much more efficient for me, it isn't for someone who hasn't spent as much time operating in the difital world.
Participant Observation	Designer(RP)	9	"At [previous company] there was less interface between designers and technicians. We handed over documents and things were built. But here at a smaller comany, we have more interaction and are more of a family than there. Brecause of that, i doubt anything like a mass hift with layoffsa would happen here. At larger companies, that might be more likely"

Fig. 3: Example Elaborated Response from Study Participant

Discussion

Introduction

Though the number of participants were somewhat limited, useful quantitative and qualitative data emerged. Demographics of participants, however, were more challenging to overcome. As a result of limited participation through LinkedIn, industry connections within Aerospace and related industries had to supplement this. As these highly technical industries face similar challenges in their labor markets due to automation and conveniences brought by 3D printing, their insights were not only valuable but perhaps more insightful than speaking only with individuals directly within the construction industry.

In general, data pointed to tangential relations being more related than first thought.. Moreover, there appears to be greater optimism regarding the future placement of laborers within construction than originally anticipated, which might make the transition into automated construction smoother than thought. There remain challenges to industry changes in construction and manufacturing, but those problems may be more so technical and about communication than

about eliminating workers entirely and making the dramatic shift within this industry that has been seen elsewhere.

Design to Manufacturing Communication

Initially, communication between designers and other parties was an afterthought to include, as it seemed only a tangential benefit to new technology. What has emerged unintentionally, however, is that there appears to be a significant problem in communication of design from the designer to those who are deciding how to build it and actually building it. As computers become increasingly ubiquitous, designers seem to be frustrated with having to transfer their information from 3D models, where they do most of their work, to 2D drawings that call out information. Doing so effectively requires many pages, correction, and time, adding cost to projects where companies already struggle to profit and perform to their customers' needs. One of the chief benefits people see of using increased automation is that machinery would not require such communication and should make things much more efficient.. Overall, it appears the process could use improvement, and doing so might bring with it many of the schedule and efficiency benefits that 3D printed construction is intended to bring without such drastic shifts in industry roles.

Automation in Industry's Effects on Workers

Although fewer people than desired were directly in the construction industry, those in similar production industries were generally optimistic that a level of balance between manual labor and automation can be reached. The commonly touted benefits of speed and safety were of course considered, but there was general agreement that at small scale manual labor is more cost

effective than full automation. These methods are seen as a tool to make their jobs easier, not so much as an enemy attempting to replace them entirely.

Efficiency was the most commonly used term throughout these interviews. Many people expect to see tremendous schedule and cost savings through the introduction of automation. It appeared it was seen as an assistant to existing infrastructure rather than a full replacement. In this case, the most time consuming parts of production, such as concrete pouring and formwork or programming and machining, are removed and those workers are otherwise allowed to do other things concurrently. No participants mentioned specifically where they thought automation might take hold first, so a more directed question would have been useful to give this.

The most unexpected comparison made here was to the trucking industry, which seems likely to be replaced by self driven vehicles in a short time. It was noted that this shift to automation is not as drastic since a majority of truckers are near retirement age and can be phased out as the new technology is implemented. This is less of a case within construction,as new, young laborers join each day, but this might point to significantly less of industry being upended than expected. If this is the case, then a phase out of many laborers into a more lean approach with fewer more skilled ones might be possible without upending things in a disastrous way. Such a balance would be appreciated when so many industries have seen layoffs recently not due to automation, but due to the pandemic and associated lockdowns. However, this demographic seems unique to the trucking industry, whereas much of the construction labor market is from immigrant laborers, across the globe (Hossain,2020 p. 5).

The data collected through both literature analysis and surveys presented an opportunity to contrast 3 distinct industries as automation gradually emerges in them. Construction and aerospace see the clear advantages 3D printing and automation can bring to industry, but not full replacement of labor. Trucking, however, automation's replacement of drivers seems to be occurring rapidly and is constantly in the news, as self driving vehicles develop. This replacement seems more permanent, as self driving trucks would reduce risks and costs associated with trucking, and there are few areas where new opportunities might emerge.

Demographics of these industries complicate direct comparison. The average trucker for, instance, is 49 years old, hence prior indications are true (Raphelson, 2018, p. 2). Construction workers are slightly younger, at 42.5 years old ('Median",2019, p. 1). While this is older than initially expected, some doubt was cast on this number, given sparse documentation. It remains true that construction workers are younger and, assuming the technologies progress at similar rates, would not have the luxury of retiring into their obsolescences. This is somewhat mitigated by the fact that they are more likely to have a modified space within the industry.

Comparison with aerospace, however, is more valid given similar demographics and that automation leaves new opportunities for those displaced by new technologies. It is easy to imagine how a construction worker formerly tasked with laying formwork for concrete could be retrained to work in tandem with a 3D printer or how a machine operator for aerospace components might be retrained to operate 3D printers. This is not the case for self driving trucks using established infrastructure. Thus, The optimistic opinions seen in the data carry through from aerospace to construction.

Conclusions

Given how automation seems to have reduced labor needs in unskilled labor in other markets, one might expect 3D printing to become a seductive force for those in industry to cut labor costs . Analysis of individuals' opinions, however, indicate that 3D printed construction would have minimal impact upon labor needs. This would improve schedule and cost by eliminating time consuming efforts, but bring with it efforts that require that same labor at different stages. In general, there appear to be encouraging benefits to efficiency of design communication, which in themselves would be tremendous improvements in the overall efficiency of the industry.

The design of this new system does seem to have an effect on the individuals, designing their behavior. Regardless of how optimistic people are now about the benefits 3D printing shows in the Western world, the same motivations and potential coercion of the nonhuman actor that appeared in other parts of the world might become apparent here. What remains to be seen, therefore, is how true the optimistic benefits many see will be upon further implementation. Published figures and plans in countries like Dubai point to a desire to reduce construction labor needs, which would devastate those employed in those regions. Based on interaction with individuals in the US, this sort of drastic shift seems less likely than differently valued parts of the world. Thus, analysis done here indicates a more bright future for 3D printed construction than initially projected, but this is dependent on the environment. Further analysis of the broader industry, especially the global market, is likely needed to be more certain of conclusions and analysis here.

Bibliography

Folk, Emily. *How Robots Are Changing On-Site Construction*. 23 June 2020, www.roboticstomorrow.com/article/2020/06/how-robots-are-changing-on-site-construction/15362.

Hossain, M. A., Zhumabekova, A., Paul, S. C., & Kim, J. R. (2020). A Review of 3D Printing in Construction and its Impact on the Labor Market. *Sustainability, 12*(20), 8492. doi:10.3390/su12208492

Latour, Bruno. "Actor–Network Theory: Bruno Latour." *Encyclopedia of Educational Theory and Philosophy*, 1996, doi:10.4135/9781483346229.n12.

Median age of US construction Workforce increases to 42. (2019, September 26). Retrieved May 02, 2021, from https://www.forconstructionpros.com/business/press-release/21071485/national-association-of-home-builders-median-age-of-us-construction-workforce-increases-to-42

Ramirez, V. B. (2020, January 27). World's Biggest 3D Printed Building Opens in Dubai. Retrieved October 25, 2020, from https://singularityhub.com/2020/01/27/worlds-biggest-3d-printed-building-opens-in-dubai/

Raphelson, S. (2018, January 09). Trucking industry struggles with growing driver shortage. Retrieved May 02, 2021, from https://www.npr.org/2018/01/09/576752327/trucking-industry-struggles-with-growing-driver-shortage

Rosen, Z., Seabrook, Bryn (advisor), & Garner, Gavin (advisor) (2020). Evolution and Societal Fears of Robotic Manufacturing. University of Virginia, School of Engineering and Applied Science, BS (Bachelor of Science), 2020: Charlottesville, VA. Retrieved from https://doi.org/10.18130/v3-3j13-zh19

Schutter, G. D., Lesage, K., Mechtcherine, V., Nerella, V. N., Habert, G., & Agusti-Juan, I.

(2018). Vision of 3D printing with concrete — Technical, economic and environmental potentials. *Cement and Concrete Research, 112*, 25-36. doi:10.1016/j.cemconres.2018.06.001

Soto, B. G., Agustí-Juan, I., Hunhevicz, J., Joss, S., Graser, K., Habert, G., & Adey, B. T. (2018).

Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall. *Automation in Construction, 92*, 297-311. doi:10.1016/j.autcon.2018.04.004

Verbeek , Peter Paul. "Mediation Theory." *Peter-Paul Verbeek Philosophy Lab*, 15 Mar. 2020, ppverbeek.org/mediation-theory/.

Verbeek, Peter-Paul. "Beyond Interaction." *Interactions*, vol. 22, no. 3, 2015, pp. 26–31., doi:10.1145/2751314.