

3D Printing Homes Impact on the Residential Construction Industry

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Construction companies are always looking for ways to reduce costs and shorten schedules and with new technologies there are more and more ways of achieving these goals. One new technology aimed to achieve those goals within the residential construction management industry is the three dimensional (3D) printer. Recently 3D printers have been put to use within the residential construction industry by printing the structures of homes, instead of framing them, at fractions of the cost and time, with greater efficiency, and less labor. 3D printed homes have a tremendous potential to impact impoverished citizens that need the peace and comfort of a roof over their head and a secure place to sleep but will struggle to make a big impact on the majority of homes in the United States. The inability of the 3D homes to reach sizes larger than an apartment (900 square feet) and the lack of an aesthetic appeal that allows for customization damages the homes potential until the technology is improved. With time and technical advancements 3D homes can become the norm of the industry but that won't be for some time as the current kinks and limitations are sorted out.

Key Words: 3D Printing, Residential, Humanitarian, Technology

Introduction

Three dimensional (3D) printing has the potential to be the next game changing technology to emerge and change the residential construction industry with videos recently making headlines because of a 3D printed home. While 3D printing has been around since the 1980's when it was known as rapid prototyping technology it continues to grow into the market and prove itself more and more useful. (Jackson, 2017) What makes 3D printing such a unique valuable technology is the way the machine constructs the material, while instead of starting with a raw material that needs to be whittled down until you ultimately get the object you hoped to create it instead builds the object up, layer by layer, until you ultimately create your intended object. The process of 3D printing continues to be implemented within manufacturing companies over traditional manufacturing techniques like subtractive manufacturing or injection molding because of the clear benefits that 3D printing brings. The 3D printing additive method reduces waste, reduces labor, reduces time, and allows for an almost unlimited amount of flexibility to be possible for the manufacturer. Even further this technology is more exciting because the impacts it can have on the construction industry more specifically the residential industry.

With the growing availability of the 3D printer and the continued growth of the technology, the 3D printer has slowly made its way into the construction industry and has the potential to affect the industry in a huge way. Within the residential sector of construction 3D printers are showing they can have a huge impact on the way homes are built for the foreseeable future. The first documented instance of the 3D printer being used in the residential construction industry was in the Netherlands with the construction of the 3D printed canal house. The project was built around a research and do system with the goal of improving the housing system worldwide. The 3D printed structure was made of different printed elements that were assembled together on-site into one building. This technique was used in order to best test the ability of the 3D printer to impact the industry and get a gauge on what it can do and how to improve it.

The second well documented implementation of the 3D printer in the residential industry happened a couple of years ago with private company in China that was able to print ten houses in a day showing the remarkable speed benefit that could be achieved this technology. The company used a prefabrication method of the 3D printer like the canal house but multiplied into sections not rooms. The Chinese company utilized a 3D-printing assembly line made up of four printers in a factory that then shipped the 3D-printed walls to site and assembled there. (Frearson, 2014) While this display showed the promise that 3D printers had within a prefabrication model, it didn't fully fulfill the promises that this technology can achieve. This example was another example showing the benefit of precast instead of the supposed benefits of 3D printing as the methods weren't different from the prefabrication of concrete elements. A further problem existed in construction of the roof which was constructed with typical means and methods because the technology isn't yet advanced enough to build a roof. While the Chinese company showed real promise with the 3D printer as a means of prefabrication the next large step in the 3D printed homes industry was made in Texas with the first site printed, permitted standing structure in America by ICON Build.

The ICON Build structure in Texas is unique because it was fully printed on site as a proof of concept and was permitted through the local agencies to be a functional building. On their frequently asked questions page ICON Build states the structure was built to a cost of ten-thousand dollars (this is only the walls) and was printed over a forty-eight hour period. Between the years of the Chinese buildings and the ICON Builder's building the technology took a leap forward with the home being able to be built on-site instead of the precast method. Further the technology showed that it is jobsite tough and can withstand downpours that typically render construction sites off-limits until the rain subsides (it rained throughout the print time according to ICON). This test also allowed for the 3D printed homes to clear massive hurdles that come with anything new in America, cutting through the red tape and many different institutions and restrictions that are prevalent during the permitting process. Clearing those hurdles gave a better sense that this technology can make an impact here in the United States for the residential construction industry.

A group of companies in the Netherlands is taking the testing of 3D printed homes ability to affect the housing market to the final level. The group consisting of the municipality of the city of Eindhoven, an engineering firm, a materials company, a contractor, a real estate manager, and the concrete printing experts at the Eindhoven University of Technology is undertaking the building of a five home community that has set the potential move in date for early 2018. This news is especially exciting given the supposed interest of the community with the realtor group claiming that they have already had twenty applicants within two days. (Kovner, 2018) This development will be interesting to follow as more information becomes known and the outcome is readily understood because it will provide a better example of if a 3D printed home or community is desired. (This article was written on June 6, 2018 and the construction of the homes has yet to begin, and for these reasons the author of this paper wasn't able to give a better account of the impact of the project.)

3D Printed Structures (On-Site)

When it comes to printing homes onsite by a 3D printer there are two different methods being used, a track based printer and a radius printer. The track based printer is guided by a track system built into the foundation allowing for the printer to move horizontally as far as the track allows while the radius printer sits in the center of the home it prints and is limited to the length its arm can extend. Given the restrictions created by the current technologies available for the printers and their varying self-inflicted restrictions 3D homes are limited to small scale structures, typically six hundred to nine hundred square feet. The 3D printer's print each company's own unique, proprietary blend of mortar layer by layer until the structure is complete. Through this process waste is reduced because there is no need for formwork or need to cut down two by fours to size and the automated process also eliminates most labor that is typically required to build a typical home. The only labor that is necessary is the labor needed to build the foundation, the roof, and any labor needed to build block-outs for windows and doors. Labor is eliminated to a large extent but given its current limitations and its layer by layer method of building, windows and doors need block-outs installed in order for the process to continue unless you want a completely enclosed structure with no natural light. One of the largest limitations to the technology currently is the inability to print the roof which ensures that additional cost will be needed to build the roof through current typical means and methods. Current printing technology also limits installation of utilities as the layer by layer process doesn't allow for electrical, plumbing, or

mechanical systems to be run through the walls. Despite these small setbacks the potential of 3D printed homes is still obvious to industry members as the amount of time to construct a home is greatly reduced along with any labor and material cost reductions provided by the technology.

This paper aims to understand the potential impact 3D printing can have on the residential construction industry. The proof of concepts being printed now are exciting and the returns are great enough to warrant a deeper dive into whether or not 3D printed homes will become the norm within the United States housing industry.

Methodology

The objectives of this case study are as follows:

- To report whether 3D printed homes will have an impact on residential construction.
- To highlight the challenges and transitional difficulties 3D printed homes face.
- To highlight the benefits of using 3D printed homes.
- To highlight the negatives of using 3D printed homes.
- To provide a recommendation on the future of 3D printed homes in residential construction.

The methodology chosen for the study was primarily qualitative. The qualitative study was done through interviews of individuals from residential construction management backgrounds. The interviews focused on 3D printed homes and the impact they can have on the residential construction workplace from each individual's point of view. The interview results were then analyzed and summarized by the researcher in order to identify and highlight the main similarities and differences. The key issues, good or bad, were then organized into the following categories: potential, challenges, and benefits. This information was then used to make a suggestion on the future impact of 3D printed homes on the residential construction industry in the conclusion of this paper.

Results and Discussion

The following information was gathered through interviews with members of the residential construction management industry. It was the goal of this study to simply gather and present the information as objectively as possible. In addition to information relating to the potential impact of the 3D printer on the residential construction industry, the current benefits of 3D printed homes, and challenges that 3D printed homes will have on the residential construction industry.

3D Printed Homes Challenges

The most discussed point of the interviews with the industry professionals was the challenges faced by 3D printed homes and what the obstacles are that limit its impact for years to come. The reasons are listed below:

1. **Aesthetics and appeal:** The 3D printed homes don't currently align with what the homebuyer in the United States want. Homebuyers in America want a home they can grow into, a home they can customize and the 3D printed homes don't allow that. The current technology, being what it is, limits the size of the home to around six hundred to nine hundred square feet not big enough for a family to grow into. Further the pure concrete structure and lack of rooms don't allow for any customization that homebuyers hope in order to make the home their own.
2. **Cost and Profit:** The cost of a printer large enough to print homes comes with a steep initial cost. Most printers large enough to print homes either aren't available on the open market or cost upwards of a hundred thousand dollars if they are for sale. In order for companies to turn a profit on the homes the market they would target doesn't match the market that would buy the homes, as the homes aren't big enough for the middle class or even most the lower class to buy and are too possibly expensive to buy for the people who would enjoy to live in one. (It was mentioned that you could possible sell the homes

to a niche market that enjoys the truly unique and different but this market is not enough to create a change to the industry.)

3. **Unknown and New Factors:** The construction industry has always been adverse to change to anything new and unknown. This along with other new and unknown things scare the industry until they are fully vetted and assured by construction companies that it won't make too great a change to their way of life or bottom line. The slow change experienced within the construction community wouldn't be anything different from any new technology trying to make headway in the industry, and 3D printed homes will not be the exception. Currently there is only one legally permitted home in the entire United States and this won't cause any company to jump on the technology until the engineering and the technology are at an acceptable level that will allow for the maximization of profits and guarantee of lower risks. The current inability of the technology to have a second floor or expand the house to a larger footprint will not help it break into the market any time soon in the United States.

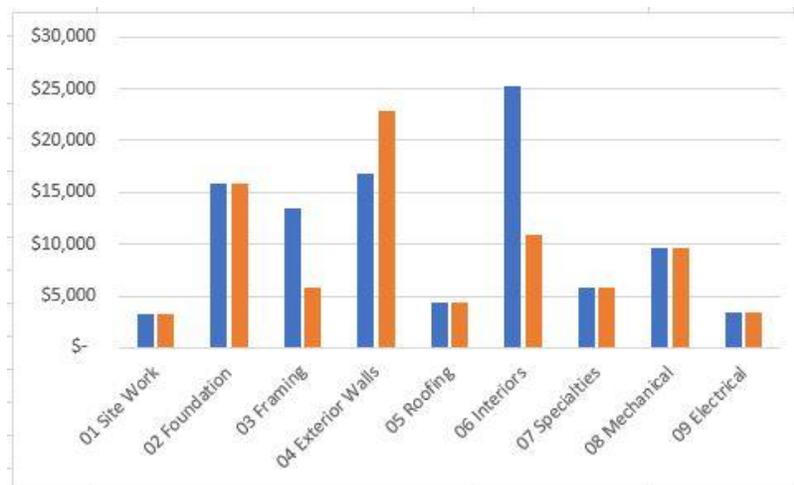
3D Printed Homes Benefits

3D printed homes provide the following benefits as according to the industry professionals:

1. **Shortened Schedule:** The faster you can build a home the faster you can sell it and create a profit. This aspect alone can make 3D printed homes a viable future alternative to stick framed homes. The technology current allows for this possibility which guarantees it can make an impact in the future and help lower the risk that comes within the homebuilding industry and the fickleness of the economy. The ability to reduce the amount of time you have your homes on the market the better, and if you can sell them and get them off your books it'll lower the company's overall risk which a huge positive to anyone in the industry.
2. **Greater Efficiency and Less Labor:** 3D printers have the added benefit of being an additive manufacturing process instead of being a subtractive manufacturing process. As was mentioned earlier in the introduction this allows for a greater efficiency in the build process and lowers the amount of waste in the build environment. Less waste leads to lower construction costs and a more sustainable project, instead of the current typical framing procedures used in home building where there is lots of lumber waste from the building of the structure. This is a huge benefit given the current state of the economy where lumber costs are reaching historical levels, the ability to reduce material cost is a much needed help. With the current tariffs and political climate lumber costs are reaching levels that are on par with the growing labor costs caused by the reduction of skilled labor in the industry and helping lead to the higher level of home costs. (Parkin, 2018) The other cost benefit achieved with 3D printed homes is the reduced need for specialized labor in the residential construction industry. Needless to say anytime you can have less people on your payroll the better the cost of the production of your project will be, and also given the less labor needed you can greater insure the quality of your project and help defend against future labor shortages.
3. **Lower Cost:** With the combination of greater efficiency, less materials, and less labor there are cost benefits to be had with using a 3D printer to build homes. In order to exemplify the possible cost savings RSMeans was used to produce a baseline estimate for an 800 square foot home that was stick framed with a stucco exterior. The cost to print the structure of the 3D printed home was estimated to be 10,000 dollars and was based off of ICON Builds 3D printed home and the cost they stated on their website. Analyzing the estimate it can be assumed that the largest cost benefit of using a 3D printer to construct homes is from the material cost. The greatest cost differential between the proposed estimates occurs in the framing and interior finishes. The seen cost benefits can be attributed to the 3D printer's ability to replace the needed stick framing typically required of a home. Eliminating the stick framing leads to the elimination of plywood and metal grate needed for the application of stucco on the exterior and eliminates the ability to install and paint drywall on the interior walls and associated costs of both processes. In the estimates the 3D printed home's exterior framing was estimated to cost more than the typical stick framed method and that was because I lumped the whole 10,000 dollar structure printing cost of the home into this category inflating the price higher than it would have been if I spilt it between exterior walls and framing..

Stick Frame	
CSI Code	Average Budget
01 Site Work	\$ 3,168
02 Foundation	\$ 15,765
03 Framing	\$ 13,372
04 Exterior Walls	\$ 16,835
05 Roofing	\$ 4,424
06 Interiors	\$ 25,307
07 Specialties	\$ 5,858
08 Mechanical	\$ 9,633
09 Electrical	\$ 3,336
Total Building Cost	\$ 97,698

3D Printed	
CSI Code	Average Budget
01 Site Work	\$ 3,168
02 Foundation	\$ 15,765
03 Framing	\$ 5,868
04 Exterior Walls	\$ 22,912
05 Roofing	\$ 4,424
06 Interiors	\$ 10,881
07 Specialties	\$ 5,858
08 Mechanical	\$ 9,633
09 Electrical	\$ 3,336
Total Building Cost	\$ 81,845



Potential of 3D Printed Homes

The potential of 3D printed homes combines the hopes of what the technology can become and the current positives of the technology:

1. **Low Income Housing and Humanitarian Work:** This is where 3D printed homes can have the largest impact on homebuilding currently as indicated by those interviewed. This technology has tremendous potential to impact those that don't need anything besides a roof over their heads and security at night. No builder can turn around and build 3D printed homes for a profit currently based off what can be learned through research, yet his shouldn't stop those that don't intend to make a profit and are just trying to help the world and create a large amount of goodwill. There are places around the world where the building restrictions are lower and the ability to mass produce these homes for those impoverished is vital humanitarian work. 3D printed homes can also be viable in the United States if a program was established by the government either for housing for those in extreme poverty or those in need of relief after a major disaster. These homes can provide much better shelters than those currently provided by disaster relief effort teams. The tents currently provided can never provide the same amount of protection or last as long as 3D printed homes which could stand long enough for any community to rebuild fully from a large disaster. Any 3D printing method would bring absolute good whether they are printed in a factory and assembled onsite or printed on-site as any rest for the weary would surely be a tremendous help to those in need.

2. Rural Jobs: Jobsites with limited access to transportation hubs can be helped by the use of a 3D concrete printer. The ability to create a concrete mortar mix onsite with resources available would be a tremendous benefit compared to shipping material like wood consistently to site. Even considering the outlandish, which ICON Build does, the possibility exists that homes can be built easily on other planets with the 3D printer because it makes more financial and feasible sense to 3D print homes than have to ship materials and labor to build homes in an extremely remote location. The 3D printer requires only a model, the printer, concrete mortar and one to two laborers instead of a whole crew and a number of supplies.

Future Research

As the technology of 3D printed homes improve, it may be beneficial for future researchers to complete additional qualitative studies to determine whether this technology will make a meaningful impact on the industry. As of now there is very little information other than articles highlighting the very best 3D printed homes can provide and sadly all these articles are written with a bias towards the companies that are producing the 3D homes because they are selling their products future worth. Also given that the technology is so new to the industry the companies pioneering the 3D printed home movement are very careful to not fully detail the workings of their product and ultimate outcomes of their test results limiting the amount of information available to make an in-depth judgement on the future of this technology. As the technology becomes better known and companies aren't as worried about their proprietary information with regard to their printers there will be a better range of data to analyze and create a much better judgement on whether or not this technology can make an impact on the residential construction industry. When the information about 3D printed homes is made more public then a future researcher can use examples of this technology to produce case studies and quantitative data to analyze the true value of 3D printed homes and better understand there future.

Conclusion

3D printed homes are an exciting technology to watch as it continues to grow over time, but with the limited knowledge currently about the new technology there are problems that hinder its current impact on the residential construction industry. The inability to produce homes that suit the largest home buying market, an unappealing design, and poor aesthetics all limit the current 3D printed homes impact. Currently the positives of a shortened schedule and lower labor and material costs simply can't outweigh the negatives to create a profitable 3D printed homes. 3D printed homes in their current iteration are best suited to humanitarian projects where providing a service is the goal and profits are not necessary. 3D printed homes as they are currently made are not suitable for the United States residential construction industry but in time they can be a force on the industry changing the way homes are built.

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