The Future of Building: The Potential Impacts of 3D Printing Within the Construction Industry

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The Future of Building: The Potential Impacts of 3D Printing
Within the Construction Industry

by

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Abstract
This research investigates the expanding practice of 3D printing in construction, focusing on its potential impacts and challenges it will face within the industry. Emphasizing both its sustainability and cost-saving benefits, this paper examines how 3D printing could potentially revolutionize traditional building methods. The ability to decrease greenhouse gas emissions, address the global housing shortage, and reduce material waste are addressed. Through interviews with industry professionals, as well as a thorough literature review, the research explores the factors driving interest and investment in 3D printing technology. Additionally, it analyzes common misconceptions regarding 3D printed structures and pinpoints areas for further research, specifically in material development and environmental considerations. These misconceptions include the idea that all 3D printed homes must look alike, or the method is “unfinished.” Through providing insights into the future market of 3D printing, this research aims to inform the overall benefits and challenges of the method in the pursuit of improved sustainable and efficient building practices.

Keywords: Sustainable Construction, 3D Printing, Greenhouse Gas Emissions, Concrete Technology, Affordable Housing, Construction Industry
The notion of employing three-dimensional (3D) printing as a method of construction often feels almost too futuristic to accept as a practical reality. It was not until 2021 that the first owner-occupied 3D printed home emerged in the United States, and by 2022, merely 129 such homes had been produced across 105 distinct construction sites worldwide. Texas is the current 3D printing leader in the United States, boasting a new community of one hundred printed homes. Despite its limited usage, the practice of 3D printing in construction is steadily gaining momentum on a global scale. Not only does this method offer a more environmentally sustainable approach to building, but it also demonstrates potential cost savings in terms of both materials and labor.

3D printing is a method of construction that is conducted by extruding mortar through a large-scale 3D printer, constructing buildings layer by layer. This research aims to dive into the promise 3D printing holds within the construction industry and explore public perception surrounding it. More specifically, how can the 3D printing lower greenhouse gases emit by traditional construction methods? Does 3D printing have the potential to improve the global housing shortage, specifically regarding low-income housing? What areas in this field require improvement for this practice to become more prevalent in the construction space?

These questions are crucial when considering such a transformative practice in an industry where conventional methods have remained largely unchanged for decades. The insights gleaned from this study will provide valuable foresight into the future of the construction industry and offer guidance on whether 3D printing is worth further investment as the world strives for greater sustainability and improved construction methods. This research aims to explore how 3D printing can revolutionize construction by addressing environmental concerns, housing shortages, and areas for improvement.
Literature Review

One of the main benefits of 3D printed buildings is considered sustainable is because it allows structures to be built using local raw materials that are available at or near the building site. 3D printing mortar can be mixed with substances such as dirt, clay, sand, or water to create the paste that extrudes from the 3D printer itself. The overall benefit from this is using cleaner materials, as well as having the ability to use these materials from the job site rather than having to transport them from far distances (Sakin and Kiroglu, 2017). Concrete production and construction already produce a large amount of greenhouse gases, therefore adding transportation of materials to work sites adds onto these staggering numbers. In addition to greenhouse gases, it also creates high amounts of solid and water waste; two things 3D printing avoids. By addressing the sustainability concerns in the construction industry, 3D printing companies can adjust their methods to enhance the abilities of their machines to align with improved practices (Kahn, Koc, and Al-Ghamdi, 2021).

Another potential effect of 3D printing on the construction industry is the potential for reduced labor. Construction proves to be a very labor-intensive field, and with that comes many safety risks. Being able to replace these labor-intensive jobs with jobs that are more involved with the automated technological process of printing will allow job sites to increase productivity, improve quality in the construction realm, improve safety, and allow a reduced reliance on human resources (Hossain, Zhumabekova, Paul, and Kim, 2020). In addition to the benefits, there are also obvious downsides to this process. Automation in construction may not be the best option for taller structures like high-rise buildings. Currently, more research needs to be conducted surrounding the load bearing abilities of the mortar. As the 3D printers currently made for construction are not equipped to create these structures, human resources are still needed until technology advances, which remains a slow process. This would require advanced printing
systems, skilled supervision, and material quality control; these are difficult to achieve as the method is looking to become more viable using what they already have.

When compared to other methods of building, 3D printing is noted to allow for a much lower construction duration time, as well as a sharp decline in carbon dioxide (CO2) emissions. In a recent comparative study, 3D concrete printing was compared to prefabricated modular construction, cast-in-situ reinforced concrete, cold-formed steel, and hot-rolled steel when creating a two-story building. The results showed that the 3D printing method reduced construction duration by approximately 95%, produces about 32% less CO2 emissions, and offers significant cost savings as compared to the other four methods. Although this highly innovative method provides significant benefits, the study still notes that there is a lack of design standard code, meaning there is a potential limitation in terms of standardization and regulatory guidance for the specific construction method (Batikha, Jotangia, Baaj, and Mousleh, 2022).

Research Questions

This study aims to explore the idea of 3D printing being a viable and sustainable alternative within the construction industry. It seeks to determine if this approach holds promise for benefits that are environmentally significant. By evaluating its potential impact on the construction sector, this research looks to determine the value of investing resources and effort into expanding this emerging market. Overall, his study aims to explore the following questions:

- Is 3D printing a viable and sustainable alternative in the construction industry?
- What are the environmentally significant benefits of 3D printing?
- Should resources and effort be invested in expanding the use of this emerging technology?

Method
In order to gain holistic insights into the 3D printing construction industry, this study will employ a mixed-methods approach which incorporates interviews with three professionals who are currently engaged in this field, as well as thorough research. A mixed-methods approach was significant to this research as the professionals give both valuable and additional insight to the minimal research done around this topic area. Individuals with diverse expertise and experience within the industry are prioritized, which will solidify a well-rounded perspective. A list of questions will guide these interviews, which allows for an in-depth exploration of key topics such as advancements in technology, current and future challenges, and future prospects. Additionally, academic resources, industry reports, and relevant literature will be studied to validate the responses obtained from the interviewees. A comprehensive understanding of the current state and future trajectory of 3D printing in construction will be collected from this research approach.

**Participants**

An e-mail was sent out to six different industry professionals regarding an interview about the 3D printing construction industry. Out of these professionals, three of them responded and agreed to participate. The three interviewees are Dan Bernard, a co-founder of MadCo3D, John Roth, the director of the John Olson Advanced Manufacturing Center at the University of New Hampshire, and Nathan Daigle, a manufacturing engineer and internship program manager at the center. The skillsets and knowledge of these professionals ensured that a well-rounded perspective of the industry would be presented.

**Procedure**
The three interviews were conducted over Zoom and lasted approximately one hour. Before these meetings, twelve interview questions were sent to the professionals to ensure they were prepared to answer them concisely. The interview questions are as follows:

1. What is your job title? Where do you work? What does your company do?
2. What made you interested in 3D printing homes/buildings?
3. Do you think 3D printing homes will continue to grow in popularity? Why or why not?
4. What factors need to change or be improved to make 3D printing a more feasible method of construction?
5. How do you believe the workforce will change if 3D printing becomes more popular?
6. In what ways does 3D printing decrease greenhouse gas emissions? Is this significant?
7. What are the pros and cons of a 3D printed structure?
8. How does the cost of a 3D printed home compare to that of a modern-day home?
9. What needs to happen for 3D printed housing to be at a price point that could provide homes for low to moderate income families?
10. What do you believe is the most common misconception about 3D printed homes/buildings?
11. What questions would you want answered about the 3D construction industry? Where do you think more research needs to be done?
12. What other key information can you share with me about the industry?

During the interviews, I asked all twelve questions in numerical order. The interviewees answered each question with as much knowledge as they had, although they occasionally had to decline questions that were not geared towards their area of expertise. Following the completion
of the questions and answers, the Zoom interview would end, and the responses were then dissected to discover key themes.

Site Visit

Prior to my interview with Dan Bernard, he invited me to visit the MadCo3D site in Rochester, NH. During this educational visit, I received a tour of the facility, in addition to seeing both the printers and examples of finished products. This site visit allowed me to gain insight into the detailed process by which the printers are guided by specialized code, the extrusion of the concrete mix, and the production of the desired final product.

I was also provided with a detailed explanation of the construction of their Hybridhouse™ (pictured below). This home innovatively combines 3D printing with current-day drywall construction techniques, aiming for optimal comfort for the inhabitants of the home. I was educated on the insulation of the walls and how the plumbing must be executed. Additionally, I was shown the integration of furniture such as seats and sinks into the design of the house, which showcases the versatility of 3D printing.
Results

As previously mentioned, each interviewee was asked a series of twelve questions to answer during the Zoom interviews. Below are answers for each question, summarized when appropriate, obtained from the three participants:

1. What is your job title? Where do you work? What does your company do?

   Dan Bernard: Co-founder of MadCo3D. MadCo3D is an architect-led 3D printing company that 3D prints homes, commercial buildings, and other structures.

   John Roth: Director of the John Olson Advanced Manufacturing Center at the University of New Hampshire. He collaborates with others to work on material development regarding 3D printing mortar.

   Nathan Daigle: Manufacturing Engineer and Internship Program Manager at the John Olson Advanced Manufacturing Center at the University of New Hampshire

2. What made you interested in 3D printing homes/buildings?
A professional perspective allowed the interviewees to note an increase in the number of companies utilizing materials for 3D printing. They were able to explain how the behavior of the concrete material makes them interested and how they want to contribute to this specialty area. The interviewees are aware of the increased interest and investment in the advancements of 3D printing technologies.

The interviewees expressed great enthusiasm for both the efficiency and creativity that 3D printing allows compared to traditional stick-building methods. The potential for cost reduction and ability to meet societal needs were emphasized during this conversation. Their interest in 3D printing derives from the opportunity to innovate in home and commercial construction, as well as the ability to decrease the reliance on skilled labor, ultimately aiming to lower the cost of building and owning a home.

John Roth, with maintenance experience and an engineering background, identifies a lack of innovation in home building. He views 3D printing as a potential solution to reducing the amount of skilled labor needed for construction, which could potentially lead to long-term cost reductions. He also emphasizes the opportunity for 3D printing to influence shelter creation and lower material usage, showing its ability to create tangible impacts within the construction industry.

3. Do you think 3D printing homes will continue to grow in popularity? Why or why not?

The overwhelming answer to this question was yes. Viable economic solutions for housing are offered through 3D printing, which increases affordability and flexible design methods when compared to traditional methods. Enhanced energy efficiency, reduced construction costs, and the ability to blend with the environment aesthetically are just some of the benefits that the interviewees highlighted. The ability to utilize readily available and local
materials further contributes to the appeal of the construction method. The expansion of 3D printing technology and the wider range of available options will naturally increase interest, which could potentially address current concerns such as the lack of sustainability in traditional housing. As for expanding low-moderate income housing opportunities, MadCo3D is currently constructing a neighborhood of forty houses in Rochester, New Hampshire to increase the amount of workforce housing available in the town. When complete, this model could potentially be mirrored for towns that are facing a similar housing shortage, paving the way for increased popularity. These houses also avoid water damage and mold that occurs in homes built with drywall, which are issues that emphasize the need for alternative building methods, further driving the demand for innovative solutions such as 3D printing.

4. What factors need to change or be improved to make 3D printing a more feasible method of construction?

The environmental impact of concrete production was mentioned during the interviews, emphasizing its major contribution to greenhouse gas emissions; therefore, they each stressed the urgent need for more environmentally friendly methods in both concrete production, and construction overall. Also, they noted challenges related to zoning laws and building codes for 3D printing, which placed a spotlight on the importance of establishing concise safety standards. Despite this, they anticipate further advancements in both hardware and software within the 3D printing sector. Ultimately, the innovative nature of this method was highlighted, and the interviewees predicted that the adoption of the method will increase as the technology becomes more user-friendly. This also comes with the need for more sustainable and efficient construction methods.
5. How do you believe the workforce will change if 3D printing becomes more popular?

The potential of 3D printing to diversify the workforce and engage workers of varying ages, genders, and physical abilities provides great advantages to the method. There is currently a shortage of workers in the concrete construction field, which could be improved through 3D printing by allowing companies the ability to hire smaller and more diverse teams. Additionally, the need for traditional trades will remain, in addition to the potential emergence of new trades related to 3D printing. It was noted that the traditional trades will have to learn to adapt to the 3D printed concrete, as it is a material tradesman will often work with in the near future. Lastly, they mentioned that although there are tasks that can be handled more efficiently with 3D printing through technical aspects such as programming and maintenance, traditional methods of building may have to often be used in the interior of these buildings.

6. In what ways does 3D printing decrease greenhouse gas emissions? Is this significant?

The greenhouse gas emissions and other negative environmental impacts created by concrete production was a major focus when answering this question. It was noted that the technological advancements in both traditional construction and 3D printing include ongoing efforts to reduce emissions. The interviewees voiced a desire for comprehensive research that would compare the lifecycle emissions of different construction methods, which would emphasize the energy efficiency of different buildings over their respective lifespans. As for environmental benefits of 3D printing, they noted reduced waste, transportation requirements, and recycled materials. Overall, the three professionals suggested that sustainability should be a major consideration in evaluating various construction methods.
7. What are the pros and cons of a 3D printed structure?

When answering this question, the interviewees highlighted the questions that remain regarding the structural integrity of 3D printed homes, as well as the potential risks associated with focusing on creativity as opposed to practicality. In addition to this, both the limited understanding of the technology's requirements and regulatory challenges are noted as concerns. Despite these concerns, the durability, energy efficiency, and quick construction of 3D printed builds were acknowledged. The need for further development in both market adaptation and multi-story construction using 3D printing was emphasized.

8. How does the cost of a 3D printed home compare to that of a modern-day home?

Factors such as design, complexity, and finishes are what determine the overall cost of 3D printed construction. In the current market, it can be considered competitive with traditional building methods, sometimes being up to 10% less expensive than traditional builds. Financial value is added through the increased speed of habitation, as well as potentially using or renting the builds commercially. As improvements in both material costs decrease and efficiencies continue, there is higher potential for 3D-printed homes to be more suitable for disaster relief and low-income housing. However, significant expenses can be attributed to mistakes made during the construction process, which ultimately depends on the expertise involved. This can make major projects much more expensive. In addition to this, mass-produced materials such as cement blocks or bricks maintain their price advantage, although 3D printed homes offer more customization advantages. Overall, the cost of 3D printing construction services depends on the unique offerings of the companies that are creating the structures.
9. What needs to happen for 3D printed housing to be at a price point that could provide homes for low to moderate income families?

A sense of urgency in implementing 3D printing construction was emphasized, although zoning challenges pose as a barrier for adoption in some areas. Acceptance in various regions requires the necessary codification to allow this method to be successful. Despite these hurdles, the affordability and energy efficiency benefits of 3D printed homes was discussed. The interviewees note the ease of replication once a successful model is established, which suggests that although upfront costs may be higher, subsequent builds could be more cost-effective overall. Dan Bernard discussed the importance of increasing the housing supply to drive down costs and mentions that MadCo3D’s Hybridhouse™ is aimed at middle-class workers. Overall, they expressed an overwhelming confidence in reducing costs and addressing low-income housing needs over time.

10. What do you believe is the most common misconception about 3D printed homes/buildings?

Common misconceptions around 3D printed buildings include the belief that all the builds must look alike, when in fact, each can be extremely different. Another misconception is that 3D printing is solely used for prototypes, and is therefore considered “unfinished” or impractical, despite the proven capability of the technology. In addition to this, the idea that the method is a novelty rather than a practicality creates a misconception regarding the feasibility and affordability of it. This lack of awareness may contribute to the reluctance of adopting the technology in the future.

11. What questions would you want answered about the 3D construction industry? Where do you think more research needs to be done?
The interviewees emphasized the necessity of research regarding creating time, labor, and cost-saving methods for affordable housing. The need for environmentally effective practices, especially in developing quick-set concretes and local sourcing to reduce environmental footprints was stressed. Lastly, the importance of establishing clear, industry-wide guidelines and further research into materials aiming to reduce greenhouse gases and improving insulation in concrete construction was emphasized.

12. What other key information can you share with me about the industry?

The versatility and speed of 3D printing technology, and its ability to work under diverse conditions, was a focal point of this response. They stressed the durability of 3D-printed structures, with Nathan Daigle noting the structures’ potential to last over 100 years with minimal maintenance, which could ultimately reduce waste over time. In short, the interviewees believe that 3D printing is on its way to mass adoption and could revolutionize construction, housing, infrastructure, and sustainability efforts, discussing its flexibility and potential for creativity.

Discussion

Growing Interest and Investment

There is a noticeable surge in companies investing in 3D printing technology for construction, which indicates a growing interest in the advancement of 3D printing technology. This development includes both technological improvements, as well as material development.
During the interviews, the professionals expressed enthusiasm for both the creative and efficient benefits of 3D printing compared to traditional methods, noting its potential to meet societal needs in new ways. As 3D printing houses is an economically viable solution for housing shortages, all interviewees agreed that they will continue to grow in popularity. In addition to this, there is a clear need for a more sustainable method of construction. 3D printing is a viable way to improve the approach and execution of the environmental side of construction.

Challenges and Areas for Improvement

In order to make 3D printing a more feasible method of construction, several challenges need to be addressed. Regulatory hurdles, such as code and zoning limitations, were a main point of concern in these interviews. Many governments are unsure of how to regulate this building process as it is so new, placing a hurdle on the advancements. In order to familiarize governments with this method, they need to see successful, real examples of this being done to investigate the opportunity for their own communities. In addition to this, societal adoption is expected to be slow, as many people do not like the style of these houses or are aware that they can be constructed. Further, tradesmen will have to be responsible for learning how to work with this concrete material as they will begin to see it more often.

Environmental Considerations

3D printing presents the potential for reducing greenhouse gas emissions in construction through reduced waste, transportation reduction, energy efficiency, and material creation. As a traditional stick-build home is being constructed, there is much waste involved in the process, as workers are disposing of scraps, damaged materials, and other various waste. When 3D printing there is minimal waste involved in the process; generally, the only waste created is the minimal
extra concrete that extrudes out when the print is complete. As the printer can be brought to the construction site itself, the amount of transportation required to bring all materials to the site is reduced, resulting in decreased greenhouse gas emissions. These homes also allow for increased energy efficiency. The concrete material ensures that the home’s interior is less susceptible to temperature fluctuations, making the need for heating and cooling much less than that of a traditional home. Lastly, the production of concrete accounts for approximately 9% of global greenhouse gas emissions annually. As the 3D printing mortar consists of a much lower concrete volume, the overall emissions are lowered. In addition to this, concrete has the potential to be ground up and repurposed instead of disposed of when being destroyed, keeping this material out of landfills and avoiding overproduction. The durability of these structures was also a main point of conversation. A 3D printed home can last from 100-300 years, whereas with a traditional stick-built home, reparations must start at a maximum of 100 years.

It is also important to note the benefits of a 3D printed build compared to a precast concrete build. Precast concrete builds are built by pouring concrete into a prebuilt mold and left there to dry. When comparing 3DCP to a precast approach, it is clearly shown that 3DCP has significant decreases in cost (25.4%), CO2 emissions (85.9%) energy consumption (87.1%), self-weight (26.2%) and an increase in productivity (48.1%). The comparison is shown in the graph below.
Misconceptions and Areas for Further Research

The idea that 3D printed structures are impractical, or the practice in unfinished, is a common misconception that prohibits adoption of the method. Many people do not know this construction method is even possible, and therefore, the idea seems too futuristic to them. People can also be reluctant to be the first to try living in these kinds of houses, and therefore, it is difficult to increase the popularity of this industry.

To make this method more feasible, research regarding material development, guidelines for construction, and environmental improvements needs to be conducted. Researchers need to find ways to make the material able to bear more load, as the ability to build larger structures is limited due to this. In addition to this, although improvements are in the works, there needs to be an even more sustainable material used to 3D print in order to have a major effect on the reduction of greenhouse gas emissions. Despite these areas of necessary improvements, as this technology continues to evolve and gain societal and professional acceptance, it is likely to reshape the way we build homes and infrastructure.
References

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https://doi.org/10.1016/j.jclepro.2020.121245


**Appendix**

**IRB Informed Consent Letter**

**INFORMED CONSENT LETTER FOR ADULT PARTICIPANTS**
**APRIL 2024**

Date: ___

Dear ___:

I am Alyssa Morrison, a UNH a senior studying Business Administration with a focus in Information Systems and Business Analytics and a dual major in Sustainability and I am conducting a research study to find out how 3D printing will influence the construction industry. I am writing to invite you to participate in this study (UNH IRB #IRB-FY2024-222).

This consent form describes the research study and helps you to decide if you want to participate. It provides important information about what you will be asked to do in the study,
about the risks and benefits of participating in the study, and about your rights as a research participant. You should:

- Read the information in this document carefully, and ask me or the research personnel any questions, particularly if you do not understand something.
- Not agree to participate until all your questions have been answered, or until you are sure that you want to.
- Understand that your participation in this study invites you to answer interview questions and will last about one hour.

I plan to work with approximately four in this study. You must be at least 18 years old to participate in this study as well as a professional within the 3D printing industry.

If you agree to participate in this study after reading this document, you will be asked to take part in an hour-long interview which will be video or audio recorded. The interview recordings will be used to describe themes or trends in the industry, as well as to provide direct quotes, in my thesis.

Although you are not anticipated to receive any direct benefits from participating in this study, the results will further the knowledge of the benefits of 3D printing within the industry. This knowledge will benefit workers within the industry due to the increased amount of research regarding the topic area.

Taking part in this study is completely voluntary. You may choose not to take part at all. If you agree to participate, you may refuse to answer any question. If you change your mind, you may stop participating at any time. Any data collected as part of your participation will remain part of the study records. If you decide not to participate or if you stop participating at any time, you will not be penalized or lose any benefits for which you would otherwise qualify.

I plan to maintain the confidentiality of all data and records associated with your participation in this research. There are, however, rare instances when I may be required to share individually identifiable information with the following:

- Officials at the University of New Hampshire,
- Regulatory and oversight government agencies, or

I will report the data within my thesis which will be published. The results may be used in reports, presentations, and publications. I will also use both direct quotes and phrases from the interviews and will attribute quotes to the participant by name and company or job title.

If you have any questions about this research project or would like more information before, during, or after the study, you may contact Russell Miles at russell.miles@unh.edu. If you
have questions about your rights as a research subject, you may contact Melissa McGee in UNH Research Integrity Services at 603-862-2005 or Melissa.McGee@unh.edu to discuss them.

Thank you for your consideration.

Sincerely,

Alyssa Morrison
UNH Undergraduate Senior