CONCRETE ADDITIVE MANUFACTURING A RESPONSE TO AMERICA'S HOUSING CRISIS

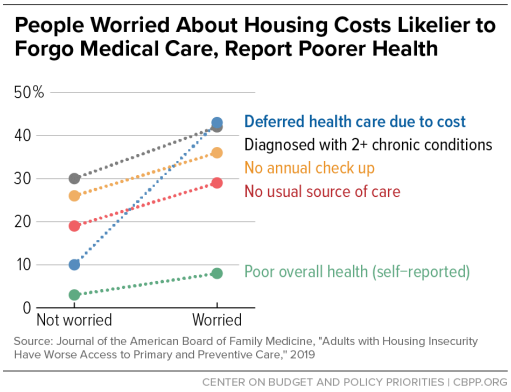
Eric Wooldridge, PE, RA, MsEng, Eldon Whitis AM Specialist
KCTCS Additive Manufacturing Center

Background

It is well known that affordable housing has become a significant issue in the U.S. due to declines in workforce, material cost inflation, and other issues; affordable housing shortages cost the United States economy over two trillion dollars annually. For example, between 1964 and 2009, affordable housing issues, on average, cost the American worker $8,775 each year. This metric can be attributed to a lack of financial mobility caused by high repair bills and medical issues due to unsafe housing.[3,10,11] These losses are frequently passed down to the younger generation through unsafe, unhealthy home lives for children, demoralizing and causing them not to meet personal goals or thrive in the classroom.[9] This is compounded by the natural disasters that continue to ravage the United States and create further setbacks in the housing market. Recurring flooding in the Appalachian regions, the increased frequency of high-strength tornadoes increasingly destroying homes in the East, and the wildfires in the West continue to march ever closer toward high-population areas.[1, 2]

Additionally, the majority of the replacement homes are constructed using lower-strength wood framing, which is not only very combustible but also very susceptible to mold, pests, and deterioration.[12] To the point that modern wood-framed homes have an expected lifespan of only 50-60 years, meaning that the home will barely outlast the original owner's lifespan.[13] Likewise, the next owner is almost guaranteed to face significant repair costs in addition to their initial purchase.[14] This is a far cry from the days when homes were built to last well over 100 to 200 years, and ownership was passed down from one generation to the next.[13]

The overall housing outlook in the United States is not good, with a housing shortage that is clearly evident and a declining workforce unable to keep up with the demand.[8, 15] The cost to rebuild a destroyed home exceeds the value of the original.[4] Insurance premiums have risen over 20% from 2023.[6] The list of issues and barriers to homeowners continues to populate.



There is even a potential link between housing and home ownership on health and wellness. Financial strains due to repairs and rising costs. Lower-quality heating and ventilation systems. These types of factors are shown to have a significant negative impact on the mental health of owners and residents.[3, 5, 16]

As housing insecurity worsens, so does overall health. As can be seen in the graph,[20] those facing housing instability are more likely to defer medical care, skip checkups, lack a usual care source, and report poor health. They also face a higher risk of multiple chronic conditions, underscoring the vital link between stable housing and healthcare access.

Though modern wood-framed homes have a number of benefits, especially in terms of speed and economy, they are becoming more of a short-term solution to the housing issues society faces today, especially when considering the relevant lifespan. However, given the obvious national need for resilient, safe, and healthy housing, it is clear that innovations are needed for the benefit of the construction industry and society as a whole.

Conventional Concrete Construction and Additive

Over time, home builders have increasingly adopted concrete construction methods to address the vulnerabilities and inefficiencies of traditional wood-frame construction. Such concrete construction is generally more durable, fire and mold-resistant, requires less maintenance, can be more energy efficient, and has a much longer useful lifespan, thus providing multi-owner savings or multigenerational benefits.[7] But, the labor for concrete

construction is intensive, the materials and formwork costs are higher, and the construction time is longer, which is a combination that often turns away potential owners.

In an attempt to reduce costs and time with automation while still taking advantage of concrete material properties, the construction industry has begun utilizing Additive Manufacturing (AM) to 3D print new homes and structures. Yet this technology also comes with its own barriers. Modern building codes do not easily accommodate AM construction methods. The majority of engineers and architects also lack the AM expertise to draft designs and blueprints of AM-constructed homes that they would be confident enough to risk their professional licenses by certifying.[17, 18] Even worse, those willing to design homes and structures that are to be 3D printed often do not use the technology to its full potential. Instead, they are designing structures with curved walls that, while visually distinct, do not necessarily maximize the potential structural performance or truly take advantage of the structural material properties beyond what is seen in conventional wood-framed residential homes. There is no emphasis on truly using AM technology in ways it was built to provide. Optimizing load-resistant shapes or using Artificial Intelligence (AI) analysis technologies to create innovative load-resisting design elements with conventionally impossible geometries that are capable of withstanding the forces of a flood or a tornado.[19] To make a structure as strong and resilient as a bunker, also be a beautiful and comfortable home.

The Solution: Expertise, Advanced Design, and Permitting

With over a decade of AM design expertise and two decades of private architectural engineering practice, the Somerset Community College (SCC) AM team has developed designs that are complementary to the true power and potential of concrete 3D printing. Using Finite Element Analysis (FEA), AI, and years of construction experience, the SCC engineers have developed structural design features that far exceed current standards and can be fully integrated into any 3D-printed home floor plan. One feature that is currently being trademarked as the "Floodbuster" allows more efficient material placement to ensure the structure has great strength exactly where it is needed in extreme stress generating circumstances such as natural disasters like floods or tornadoes. For example, integrating Floodbusters into a building floor plan design that is square or rectangular can increase its general strength to potentially withstand the forces generated by an EF4 tornado or a high-velocity flood. Better yet, the relative cost of concrete 3D printing a building using these designs is comparable to a traditional home made from concrete blocks. Additionally, the SCC team has determined a streamlined methodology for receiving building code permitting approval of these structures in compliance with the prevailing International Building Code, which is the foundation for the majority of the nation's individual building code jurisdictions.

Broader Impacts

The broad adoption of concrete 3D printing, led by AM-fluent engineering teams like those at the SCC, can provide extensive solutions to the housing crisis. Post-disaster recovery can be revolutionized with the ability to print durable long-term shelters quickly; low-income communities would feel some relief by taking advantage of efficient, clean, sustainable structures; and disaster-prone regions could prepare for increasingly frequent extreme weather events well in advance.

Because of the structural longevity, economic savings through these advancements would have generational effects as homes could once again be effectively passed down through family members; multiple owners can take possession over the home's lifespan without significantly reinvesting in the structure for repairs and significant upkeep; and government assistance funds could be focused on future innovations instead of continuous rebuild projects. Helping the American people to thrive with affordable, trustworthy homes that are as durable and resilient as the people that dwell in them.

3D concrete-printed floodbuster home

See appendix for references, provided separately from this document.

CONCRETE ADDITIVE MANUFACTURING A RESPONSE TO AMERICA'S HOUSING CRISIS

Eric Wooldridge, PE, RA, MsEng, Eldon Whitis AM Specialist
Somerset Community College

Appendix

1. "Climate Change and Property Insurance Claims." *Vertafore*, www.vertafore.com/resources/blog/climate-change-and-property-insurance-claims#:~:text=The%20increases%20in%20frequency%20and,certain%20high%2Drisk%20markets%20altogether
2. US Department of Commerce, NOAA. "Is Tornado Frequency Increasing in Parts of the U.S.?" *National Weather Service*, NOAA's National Weather Service, 17 Oct. 2018, www.weather.gov/lmk/niu_tornado_frequency_study#:~:text=After%20removing%20non%2Dmeteorological%20factors,record%20has%20remained%20relatively%20constant
3. Braveman P, Dekker M. "Housing and Health." *RWJF*, 20 June 2023, www.rwjf.org/en/insights/our-research/2011/05/housing-and-health.html
4. Team, Insurance. "Explaining to Homeowners Reconstruction Costs versus Other Valuations." *CoreLogic*®, 18 Sept. 2023, www.corelogic.com/intelligence/explaining-to-homeowners-reconstruction-costs-versus-other-valuations/
5. Krieger, James, and Donna L. Higgins. "Housing and Health: Time again for public health action." *American Journal of Public Health*, vol. 92, no. 5, May 2002, pp. 758–768, https://doi.org/10.2105/ajph.92.5.758
6. Lizknueven. "Where Homeowners Insurance Rates Have Risen the Most." *CNBC*, CNBC, 14 Oct. 2024, www.cnbc.com/select/homeowners-insurance-skyrocketing-how-to-lower-premium/
7. Marden, David. "The Rise of Multi Generational Homes and Granny Pods: A Solution for Modern Families." *OpenHausRealty.Com*, 28 May 2024, www.openhausrealty.com/blog/the-rise-of-multi-generational-homes-and-granny-pods-a-solution-for-modern-families/
8. Sequeira, Robbie. "The US Needs Homes. but First, It Needs the Workers to Build Them. • Stateline." *Stateline*, 6 Feb. 2024, stateline.org/2024/01/24/the-us-needs-homes-but-first-it-needs-the-workers-to-build-them/#:~:text=The%20construction%20industry%20says%20it%20is%20experiencing%20a%20workforce%20shortage.Contractors%2C%20a%20national%20industry%20group
9. "Why We Care." *National Low Income Housing Coalition*, nlihc.org/explore-issues/why-we-care#:~:text=Moreover%2C%20each%20dollar%20invested%20in,supports%20job%20creation%20and%20retention
10. Freixas, Xavier, and Anthony M. Santomero. "An overall perspective on banking regulation." *Working Paper (Federal Reserve Bank of Philadelphia)*, Feb. 2002, https://doi.org/10.21799/frbp.wp.2002.01
11. Divringi, Eileen. "Why Organizations Should Invest in Home Repairs to Improve Health " NCRC." *National Community Reinvestment Coalition*, 5 Mar. 2020, ncrc.org/why-organizations-should-invest-in-home-repairs-to-improve-health/
12. "5 Common Issues with Wood Framing Construction." *Quantify*, 6 Dec. 2024, quantifyna.com/sb/5-common-issues-with-wood-framing-construction/#:~:text=Time's%20Toll%3A%20Durability%20and%20Longevity&text=Over%20time%2C%20wood%20tends%20to,weather%20doesn't%20help%20either
13. "Architectural Longevity: What Determines a Building's Lifespan?" *Edgerton Center*, architecture.mit.edu/news/architectural-longevity-what-determines-buildings-lifespan#:~:text=The%20average%20lifespan%20of%20a,years%2C%20from%20construction%20to%20demolition
14. "Life Expectancy of Home Components." *Optimal Home Inspections*, optimalhomeinspections.com/resources/standards/life-expectancy-of-home-components/
15. *How Do Labor Shortages Affect Residential Construction ...*, www.haas.berkeley.edu/wp-content/uploads/Howard_Wang_Zhang_Housing-Supply-and-Construction-Labor-Dayin-Zhang.pdf
16. Burdette, Amy M, et al. "Household Disrepair and the Mental Health of Low-Income Urban Women." *Journal of Urban Health : Bulletin of the New York Academy of Medicine*, U.S. National Library of Medicine, Feb. 2011, pmc.ncbi.nlm.nih.gov/articles/PMC3042082/#:~:text=Individuals%20living%20under%20poor%20

See appendix for references, provided separately from this document.

housing.perceptions%20of%20their%20home%20environment.&text=In%20this%20way%2C%20substandard%20housing,consequence%2C%20poorer%20mental%20health%20outcomes

17. "Concrete 3D Printing Explained: The Benefits and Challenges." *Qualitest*, 26 Sept. 2024, www.worldoftest.com/articles/concrete-3d-printing-explained-benefits-and-challenges#:~:text=While%20traditional%20methods%20involve%20formwork,that%20were%20once%20nearly%20impossible
18. Pall, Lisa. "Advantages and Disadvantages of a 3D Printed House." *COBOD*, 12 June 2023, cobod.com/advantages-and-disadvantages-of-a-3d-printed-house/
19. "Pros and Cons of 3D Printed Construction." *Architect Outsourcing*, architectoutsourcing.com/pros-and-cons-of-3d-printed-construction/
20. *Chart Book: Housing and Health Problems Are Intertwined. ...*, www.cbpp.org/research/health/housing-and-health-problems-are-intertwined-so-are-their-solutions

See appendix for references, provided separately from this document.