The feasibility of 3D printing for single-family dwellings: An analysis using venture capital criteria

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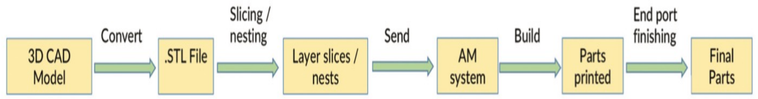
SSM1100Y: Research Paper

Introduction & Background

- Home building virtually unchanged over the last century.[1]
- Three-dimensional printing (3DP) manufactures physical objects layer upon layer based on a digital model.



- 3DP has demonstrated it can reduce material consumption, waste generation, and energy use vs. traditional construction methods[2] - yet 3DP not commercially available or widespread in market to date.
- Venture capital (VC) investors play critical role in providing start-ups with funding to attain commercial-scale development.[3]

Research Question & Objectives

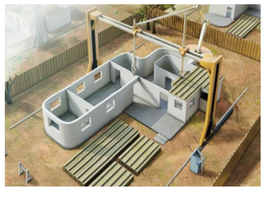
How does 3D printing of building components for single-family dwellings align with investment criteria for climate technology venture capital?

Objectives:

1. Evaluate VC industry and climate tech investment criteria.
2. Based on criteria, analyze advancements, limitations, and gaps in 3DP construction of single-family dwellings.
3. Discuss how advancements and limitations justify, or do not, VC investment.

Methodology

- **A comprehensive literature review of 120+ sources.**
  - Peer-reviewed journal articles; books by experts in the field on VC, climate tech, buildings and 3DP; reports by consulting organizations, industry associations and government agencies.
  - Not limited to any specific geography given relative novelty of literature.
- **Supplemented by interviews with three professional VC investors targeting the built environment.**
  - Two of three investors focusing on climate tech start-ups.



Literature Review & Results

Part I: Overview of Climate Tech & Venture Capital

- Climate Tech: solutions that enable us to understand, mitigate climate change and adapt to its impacts.
- Early-stage companies with novel, unproven tech often perceived as too risky to provide debt finance.
- VC investors can provide cash flow and other value-added contributions

- **Primary criteria identified for this study:**
  1. Technology advancements, limitations
  2. Climate impact
  3. Large and growing market
  4. Competitive strategies

Part II: Overview of Buildings

- Two sources of GHG emissions associated with buildings[4]:
  - Upstream (57%) and onsite (24%) emissions - associated with building operations (e.g., lighting, heating, and cooling).
  - Embodied emissions (18%) - associated with building materials (e.g., extraction and production, assembly and disassembly process, transportation).

- **Growing relevance of GHG emissions associated with embodied emissions.**
- Construction of new floor area expected to double global building stock by 2060 – equivalent of building a New York City each month for next 40 years.

Part III: 3DP of Building Components for Single-Family Dwellings

1. Technology

Software

- Building information modeling facilitates information exchange of a 3D digital model.[5]

Hardware[6]

Gantry-based *Single arm-based*


Materials

- Cementitious-based
- Polymer-based
- Metallic-based

Housing Construction Applications

- Material extrusion method: Contour Crafting & Concrete Printing.[7]
- Binder jetting method: D-shape.[8]

2. Impacts

Climate

- Up to 38% of Portland cement could be phased out by fly ash and silica fume in 3DP concrete mixture.[9]
- Lower waste generation by 30-40% due to removal of formwork.[10]
- Need to improve materials sustainability and further LCA research recommended.

Construction Process

- Eliminates labour time needed for formwork installation & removal (60% of build time).
- Mitigates human error (80% of housing construction errors).
- Alleviates burden caused by labour shortages.

Economic

- Project cost reductions of 40-50% vs. traditional concrete house. [11]
- High upfront & unclear maintenance costs.
- Continuing R&D needed to be cost-effective.

3. Market

- Global construction industry largest in the world, yet one of least digitized owing to fragmented value chain, low margins, and risk aversion.[12]
- Led to historical underperformance – one third of average global economy across last 20 years.
- Industry size and regional building codes point to co-existence of multiple tech solutions.
- Global market size for 3DP construction forecasted to grow 100.7% per year over next decade and reach US$ 5 billion by 2030, driven by affordable housing and labour shortage.[13]

4. Competitive Strategies

- 3DP players increasingly pursuing a business-to-business (B2B) model & collaborating with real estate development firms.
- Evidence supporting both off-site (prefabrication) and on-site strategies. Capital intensity can be mitigated by outsourcing factory sites to de-risk.
- Patents related to software, hardware, and materials to play important role in 3DP housing.

Conclusion & Key Takeaways

- **Gantry-based extrusion of cementitious-based materials, enabled by BIM**, represents advanced 3DP tech with ability to help tackle global affordable housing and labour shortage.
- Potential to mitigate embodied emissions associated with single-family dwellings. Clear construction process advantages, though ongoing R&D needed to be cost-effective alternative.
- Both off-site and on-site printing supported, coupled with B2B model and intellectual property.
- Taken together, developers well-positioned for climate tech VC.

References

[1] Sakin, M., & Kiroglu, Y. C. (2017). 3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM. *Energy Procedia*, *134*, 702–711. https://doi.org/10.1016/j.egypro.2017.09.562
[2] Schuldt, S. J., Jagoda, J. A., Hoisington, A. J., & Delorit, J. D. (2021). A systematic review and analysis of the viability of 3D-printed construction in remote environments. *Automation in Construction*, *125*(February). https://doi.org/10.1016/j.autcon.2021.103642
[3] Shakeel, S. R., & Juszczyk, O. (2019). The Role of Venture Capital in the Commercialization of Cleantech Companies. *Management*, *14*(4), 325–339. https://doi.org/10.26493/1854- 4231.14.325-339
[4] IPCC. (2022). *Sixth Assessment Report*. https://www.ipcc.ch/assessment-report/ar6/
[5] Wu, P., Wang, J., & Wang, X. (2016). A critical review of the use of 3-D printing in the construction industry. *Automation in Construction*, *68*, 21–31. https://doi.org/10.1016/j.autcon.2016.04.005
[6] Li, M., Zhang, X., Tay, Y. W. D., Ting, G. H. A., Lu, B., & Tan, M. J. (2022). Three- dimensional (3D) printing for building and construction. In *Digital Manufacturing*. INC.
[7] Craveiro, F., Duarte, J. P., Bartolo, H., & Bartolo, P. J. (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. *Automation in Construction*, *103*(April), 251–267. https://doi.org/10.1016/j.autcon.2019.03.011
[8] Al Rashid, A., Khan, S. A., G. Al-Ghamdi, S., & Koç, M. (2020). Additive manufacturing: Technology, applications, markets, and opportunities for the built environment. *Automation in Construction*, *118*(May). https://doi.org/10.1016/j.autcon.2020.103268
[9] Chen, Y., Veer, F., & Çopuroğlu, O. (2017). A critical review of 3D concrete printing as a low CO2 concrete approach. *Heron*, *62*(3), 167–194.
[10] Verhoef, L. A., Budde, B. W., Chockalingam, C., García Nodar, B., & van Wijk, A. J. M. (2018). The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach. *Energy Policy*, *112*(November 2017), 349–360. https://doi.org/10.1016/j.enpol.2017.10.034
[11] Wang, B. T., & Rimmer, M. (2021). 3D Printing and Housing: Intellectual Property and Construction Law. In *Automating Cities: Design, Construction, Operation and Future Impact*. Springer. https://doi.org/10.1007/978-981-15-8670-5
[12] Ribeirinho, M. J., Mischke, J., Strube, G., Sjödin, E., Blanco, J. L., Palter, R., Biörck, J., Rockhill, D., & Andersson, T. (2020). *The next normal in construction: How disruption is reshaping the world's largest ecosystem*. McKinsey & Company.
[13] Grand View Research. (2023). *3D Printing Construction Market Size, Share & Trends Analysis Report*. Grand View Research.