

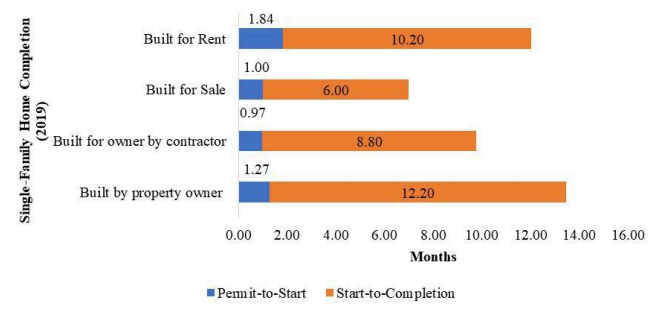
**2024 Undergraduate Sustainability Case**

**Ensuring Housing for All:**   
**Solutions for the Housing Crisis in Communities**

Austin, Texas-based Icon Technology Inc. (Icon) won Fast Company’s 2020 World Changing Ideas Awards in the general excellence category (Peters, 2020). The Fast Company presented its award to Icon because its 3D printing offers a potential solution to the global housing affordability problem for the poorest in society (Peters, 2020). Jason Ballard, co-founder and CEO of Icon, said, “Icon was born out of frustration with the housing situation” (Visram, 2021). Icon homes are energy-efficient, built faster compared to those built of concrete masonry, and create less waste in the construction process (Paleja, 2021).

Furthermore, 3D-printed houses built by Icon comply with the International Building Code (IBC). Its homes can bear extreme weather conditions and remain durable for as long as conventionally built homes such as those built from wood or brick (Paleja, 2021). Ballard said, “Construction-scale 3D printing not only delivers higher-quality homes faster and more affordably, but fleets of printers can change the way entire communities are built for the better” (Paleja, 2021). See Figure 1 for the time of completion of a single-family home in the United States in 2019.

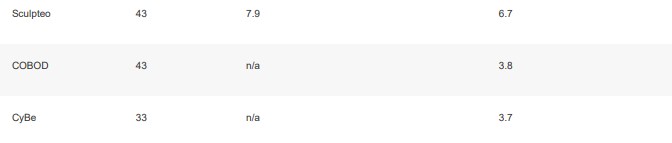
Figure 1. Time of Completion of Single-Family Homes in the United States (2019)



Source: Developed by the authors based on information available at NAHB (2020).

Industry experts believe that 3D printing in housing is disruptive to the industry (Yakemchuk, 2021). However, other experts believe that, although 3D printing could reduce construction costs, the ownership cost of a house may remain the same as the cost of land may increase (Hartman, 2021). Competition in 3D printing is also growing (see Table 1) and, globally, customers, governments, etc. are showing interest in adopting 3D-printing technology in housing (Molitch-Hou, 2016).





Source: Developed by authors based on information available at: Owler (2021).

All figures are for the year 2021.

**Background**

Icon was co-founded in late 2017. Since its inception, Ballard maintained that the company was motivated by the global housing crisis and the dearth of solutions to address the problem. He intended to combat the affordable housing problem using 3D printers, robotics, and advanced materials. In 2018, Icon constructed a 350-square-foot house within 48 hours (Azevedo, 2021). The company worked with a non-profit partner, New Story, fabricating the USD 4,000, 350-square-foot house in Texas as an early proof-of-concept for investors. Experts believed Icon’s technology leveraged 3D printing to offer “better value” than conventional housing construction methods.

At first, Icon prioritized developing houses for the homeless. The company took five to seven days to complete each housing project in Texas, which was first inhabited in the summer of 2021. Icon worked with several partners in the housing market. For example, Logan Architecture designed the house, including vaulted master bedrooms, private offices, and a minimalist rustic aesthetic. By March 2021, Icon had 40 employees. The company forecast that by the end of the year, it would have a workforce of 100.

**Background of 3D Printing**

3D printing has been in practice since the 1980s. It is expensive, with the cost of 3D-printing machines for building houses ranging from USD 180,000 to USD 1 million. Technologists developed the process of 3D printing, also known as additive manufacturing, as an alternative to other industrial manufacturing techniques, such as extrusion and casting. Additive manufacturing proved to be an effective way to make complex mechanical parts like wind turbines. The aerospace and medical industries use 3D-printing technology for prototyping. Although quite common in business-to-business (B2B) industries, 3D printing was introduced in the consumer housing sector for the first time in 2017 and was both affordable and had enhanced functionality. The Economist describes processes in 3D technology as:

First you call up a blueprint on your computer screen and tinker with its shape and color where necessary. Then you press print. A machine nearby whirrs into life and builds up the object gradually, either by depositing material from a nozzle, or by selectively solidifying a thin layer of plastic or metal dust using tiny drops of glue or a tightly focused beam. Products are thus built up by progressively adding material, one layer at a time: hence the technology’s other name, additive manufacturing. Eventually the object in question—a spare part for your car, a lampshade, a violin—pops out….

The automotive industry uses 3D printing for manufacturing vehicle parts. For example, Phoenix, Arizona-based Local Motors developed the electric vehicle “Strati,” heavily relying on 3D printing. 3D printing was used to create different types of large-scale structures, ranging from multi-story buildings to gigantic turbine towers. In June 2020, General Electric utilized 3D-printing technology developed by COBOD (Construction of Buildings on Demand, a Danish firm), in its renewable energy division to construct “record-tall” wind turbine towers. Moreover, there is also an acute labor shortage in the home-building industry. 3D-printed homes require few workers, as the printer does the bulk of the construction.

**Icon’s Innovative Technology**

Icon’s construction capabilities are built around its proprietary Vulcan 3D printer. Vulcan is a 10-by-35-foot printer. Icon specifically designed the printer to produce buildings quickly and affordably with maximal design flexibility. Vulcan printing employs a robotic printing technology that prints a layer 10 inches per second, which allows for quick completion of manufactured goods and construction, commonly within seven days. The width and print capacity of Vulcan are adjustable, allowing the construction of an entire 2,000-square-foot house in one piece. The Vulcan technology is also compatible with various slab sizes, enabling users to construct houses flexibly in a variety of layouts. Vulcan can also be transported and deployed without any need for assembly.

Lavacrete is ICON’s proprietary concrete mix. Icon’s 3D printer extrudes Lavacrete, which is prepared in a large concrete mixing machine. Ballard mentioned that concrete-based houses are sturdier than timber. The materials used are cheaper and cut overall costs by 10% to 30% compared to the traditional construction model. The printer, to construct a 3D house, pours layers of Lavacrete in long swirls, one after another. The Lavacrete material makes the homes both energy-efficient and more resistant to fire, flooding, and high winds than regularly constructed houses. The houses can also withstand an earthquake of magnitude 7.4 on the Richter scale.

Prefab 3D- printed houses also address the affordable housing problem. However, for very large, prefabricated parts, transportation costs outweigh the benefits.

**Icon’s Growth Strategy**

In 2020, Icon received USD 35 million of series A financing, led by Moderne Ventures. Together with previous funding that began in 2018, the Moderne Ventures investment raised the Icon total funding value to USD 59 million (Olick, 2021). Icon’s seed round investors included Oakhouse Partners, Cielo Property Group, D. R. Horton (the largest homebuilder in the United States), and real estate developer Emaar group, among others. In August 2021, Icon received USD 207 million of series B funding, which was led by Norwest Venture Partners (ICON Technology Inc, 2018). Commenting on the funding, Ballard said, “The series B funds will go toward more construction of 3D-printed homes, rapid scaling and R&D,” further space-based tech advancements, and creating “a lasting societal impact on housing issues”.

In 2021, in East Austin, Texas, Icon, for the first time, put up for sale four multi-story mainstream 3D-printed buildings, at a starting price of USD 450,000. Icon partnered with real estate developer 3Strands and used its Vulcan 3D printers to construct four multi-story buildings. Gary O’Dell, co-founder and CEO of 3Strands, said, “We want to change the way we build, own and how we live in community together.” O’Dell added, “This project represents a big step forward, pushing the boundaries of new technologies and 3D printed homes” (Hanaphy, 2021). On the price tag of USD 450,000, Jarett Gross, an industry expert, noted that some journalists falsely claimed USD 10,000 as a potential price of a 3D-printed house, and that this value did not reflect reality (Hartman, 2021). Icon’s other housing project at the time was a collaboration with a nonprofit organization, Mobile Loaves & Fishes in Austin, which aimed to help homeless people find a place to live (Waldek, 2021). Taylor Jackson, Icon’s head of construction, said,

“While ICON is still in its early stages, the company’s aim is to work with many builders, developers, architects, and organizations to utilize ICON’s technology to build homes of many sizes, at varying price points, and with ultimate design freedom to create anything you can dream up”. (Waldek, 2021)

By 2022, Icon continued to explore additional facets of environmental sustainability, to demonstrate the quality of its houses, and continue the goal of helping those who cannot afford good housing. For example, the Icon housing plan for 2022 was expected to include photovoltaic roofs for solar energy and to enhance the sustainable features of the houses (Paleja, 2021). In terms of building quality, in a part of Mexico shaken by an earthquake, Icon houses sustained no damage, offering assurance of the quality of its houses. Furthermore, because the houses were constructed of concrete, they were resistant to mold, termites, water, and rot (Olick, 2021). In Tabasco, Mexico, Icon, in partnership with New Story and ÉCHALE, constructed a neighborhood of 3D-printed homes. Each of the houses in the community was 500 square feet and intended for needy citizens (Glover, 2019).

Icon is also working to upgrade the speed of its 3D printer Vulcan. The new version of the printer is believed to be twice as fast as the earlier version and can construct houses 1.5 times larger, as large as 3,000 square feet (Azevedo, 2021).

Apart from building affordable houses for the poor, Icon has developed a variety of structures for various institutions. For example, Icon produces massive “vehicle hide structures” for the U.S. Marine Corps. Also, the National Aeronautics and Space Administration (NASA) contracted Icon to produce a system for 3D-printed houses on the moon and Mars under a simulated environment (Hanaphy, 2021; Olick, 2021). The moon and Mars have challenging atmospheres, and their concrete had to be selected based on the geology of the celestial body. Though a housing crisis exists on Earth, Ballard decided to collaborate with NASA as he believed it was necessary to address Earth-centric problems such as homelessness. He said, “I think the kind of civilization that learns to explore outer space, and to live in outer space, will be the civilization that is able to solve homelessness” (Visram, 2021).

**Competition and Competitive Advantage for ICON**

Icon faces competition from several other 3D house printing companies working with different housing construction companies. One of its 3D-printing competitors is California Mighty Buildings, which builds 3D houses more sustainably than Icon (Olick, 2021). COBOD and WASP are other significant competitors (see Table 1). In late 2020, the PERI Group of Germany, a housing construction company, allied with COBOD and built a three-floor commercial apartment using COBOD’s large-format machines (Hanaphy, 2021). WASP took an eco-friendlier approach by introducing sustainable housing based on the circular housing model concept (Hanaphy, 2021). Massachusetts-based Apis Cor, yet another construction company, also has intentions to use the 3D-printing machine to build affordable housing in the U.S. states of Florida, Louisiana, and California (Dezeen, 2019).

In March 2021, California-based Mighty Building, in alliance with housing developer Palari Group, announced that it would construct 15 3D-printed homes in what it deems “the world’s first planned community of 3D-printed homes … centered around the integration of technology and sustainability” (Olick, 2021). Mighty Buildings also claimed that their 3D-printing process reduced construction waste by 99% and was 30% to 40% cheaper than traditional construction (Olick, 2021). These improvements are the result of a new polymer composite, created by the company, that resembles a synthetic stone.

3D housing construction companies also differ in their construction approaches. Mighty Buildings, unlike Icon, makes homes in panels in a factory, where the company also assembles houses (Olick, 2021). Alexey Dubov, co-founder and chief operating officer of Mighty Building, said, “We are serving customers all across California so we are 100% sure that our homes can withstand earthquakes or wind. The only exception is hurricane tests are not completed” (Olick, 2021). Mighty Buildings was testing its material to assess its ability to withstand hurricane-force winds (Olick, 2021). Mighty Buildings has made units with as many as three bedrooms for less than USD 300,000, to be delivered by the end of 2021 (DeMuro, 2020).

**3D Construction Globally**

In addition to activity in the United States, 3D printing is occurring in several locations around the world. A few of those are discussed here.

*Dubai*

In 3D printing, Dubai, an important city in the United Arab Emirates, is a nation of skyscrapers, and is aspiring to become a global center for 3D-constructed houses (Morely, 2017). The United Arab Emirates has a history of grand, futuristic architectural experiments. Dubai also has rich financial resources and the political will to develop a viable 3D-printed housing industry (Morely, 2017). Dubai aims to build 25% of its city’s buildings by 2030 based on 3D techniques (Molitch-Hou, 2016). Apis Cor, a robotic construction company, used its technology to construct a 3D-printed building in Dubai. It measures 9.5 meters high with a floor area of 640 square meters (Meisenzahl, 2019). The printing took place in the open and proved that the technology could handle a desert environment without humidity and temperature control (Meisenzahl, 2019).

*Germany*

In September 2020, Germany constructed its first 3D-printed residential building in Bavaria, southern Germany (Ozdemir, 2021). The building accommodates five flats over three floors. For construction, the designers used a COBOD printer called BOD2, and construction was completed in five weeks (Ozdemir, 2021).

*India*

In 2019, Larsen and Tubro, India’s largest construction company, built a 3D-printed one-story building, followed in 2021 by a two-story building (Sertoglu, 2021). COBOD supplied the 3D printer. The houses were made of a 3D-printable concrete mix developed by L&T’s in-house team (Sertoglu, 2021). India is striving to construct 60 million homes as part of the “Housing for All by 2022” program, and 3D printing could contribute significantly to achieving this goal (Sertoglu, 2021).

**Challenges of 3D-Printed Houses**

In a 2021 survey by Realtor.com, 66% of 3,026 respondents answered that they would be willing to buy a 3D-printed house. Also, 75% of millennial respondents were affirmative (Flynt, 2021). Although the survey suggests openness to 3D-printed houses, there are challenges 3D-printed house companies face.

3D printers have small print chambers that restrict the size of parts that can be printed. Products larger than the typical small capacity need to be printed in separate parts and then joined together or assembled. This potentially increases both costs and time (TWI, 2019). Yet another problem with 3D printing is that it is directly related to the type of machine or process used. Some printers have lower tolerances, implying that final parts could differ from the original design (TWI, 2019).

Experts consider Americans set in their ways in terms of their ideas of what constitutes a house. This “snobbishness” may restrict the potential clientele for 3D-printed houses (Waterworth, 2021).

There are some health concerns associated with 3D-printed houses (Micu, 2020). A team of scientists found evidence of ABS (acrylonitrile butadiene styrene) emissions generated during the printing process that could affect human lung cells, causing “moderate” toxicity in those cells (Micu, 2020). Peter Byrley, one of the scientists involved in the study, noted, “To date, the general public has little awareness of possible exposures to 3D printer emissions,” and emphasized the need “to increase public awareness of 3D printer emissions, and of the possibly higher susceptibility of children” (Gajewski, 2020). 3D printing has environmental consequences as well. Joana Marie Sipe from Duke University found that the biproducts from the plastics made by the 3D printers are damaging to the environment as minute pollutant particles are released into the environment during construction (Gajewski, 2020).

**Impact of 3D Constructed Housing on the Real Estate Market**

Some experts—considering housing globally—suggest that with the increase in the number of 3D-printed houses, housing price inflation will likely level off by the mid-2030s. In contrast, according to other experts, such as Tal (2021), it could also deflate because speculative homeowners may “begin to sell their surplus properties en masse” (Tal, 2021). Consequently, there could be a sharper decline in housing prices, with the housing market becoming a buyers’ market, a phenomenon likely to happen for the first time in decades (Tal, 2021). Experts believe that, by 2040, housing would become so plentiful that it may become a commodity market (Tal, 2021). They also expect the housing market to lose its investment appeal at some time in the future (Tal, 2021).

However, if 3D-printed housing becomes popular, land prices are expected to increase. Experts believe this will happen as people or developers may want to build larger houses or apartments by buying more space, as the construction cost would have decreased (Hartman, 2021). The Virginia Center of Housing Research at Virginia Tech University suggested that a three-bedroom and two-bath 3D-printed house in South Richmond, Virginia, could be sold for between USD 210,000 and USD 220,000 (Flynt, 2021). Through traditional construction technology, the 2021 prices for similar houses in the area stood at a median price of USD 310,000 (Flynt, 2021). Therefore, property developers planning on constructing new property will need to buy land. However, if demand for 3D houses increases, but land supply is low, land prices will increase, which will increase the total cost of construction as developers would need to spend more money on land purchase. Eventually, the cost of 3D-printed houses may increase, bringing it on a par with the cost of traditionally constructed houses.

**The Road Ahead**

The 3D-constructed housing market is growing globally (Hanaphy, 2021). According to Icon CEO Ballard, the United States has a shortage of five million homes that need to be built quickly but “without compromising quality, beauty, or sustainability,” which is made possible with 3D-printing technology (Paleja, 2021). 3D-printed houses are also expected to capture mainstream housing construction. O’Dell of 3Strands said, “ICON has delivered better homes at a better value across a variety of cost-centers than conventional construction, including materials, time to market, and labor” (Hanaphy, 2021). Commenting on mainstream housing developed by Icon in Texas, he said, “The East 17th St residences represent the future of home-building for the mass market and illustrate what is possible with this technology” (Hanaphy, 2021).

Furthermore, M. V. Satish, Director and Senior Executive Vice President of Buildings at L&T, India, considers 3D printing to be disruptive. He said, “3D concrete printing is one of the technology disruptors with the potential to radically redefine construction methodologies” (Sertoglu, 2021). Icon’s future include the delivery of social and disaster relief housing and more mainstream housing (Azevedo, 2021). Ballard also intends to continue developing construction systems for creating habitats on the moon and eventually Mars, in association with NASA (Azevedo, 2021). With scalability already being a problem, is Ballard trying to achieve too much?

**Your Consulting Team’s Assignment**

Your team must address the question: **How do you make 3D printing a sustainable solution in your community?**

You know your community and your community will be the focus of your team. The key decision-makers at your community are your audience. You must convince them of your solution.

**Guidance on Selecting Your Community of Choice**

First, let’s define what we are referring to. Because we have teams participating from a wide range of locations, we leave that up to you.

Therefore a “community of choice” is defined as *the specific geographic setting plus the specific targeted underserved population(s) your consulting team will be focused on*. For example, a team might focus on a specific neighborhood they know well in Pittsburgh or Baltimore and within that neighborhood a particular racial/ethnic group(s) such as the Latinx, Indigenous or African American community.

Advice on selecting your “community of choice”:

* *Be specific and don’t bite off more than you can chew* – we do NOT recommend you choose an entire state or region or city; be specific and focus on a particular area
* *Be realistic and make sure it is a place your team knows well* – we recommend you select a geographic location that your team is familiar with and can access information about
* *Focus but don’t lose sight of replicability* – Icon recognizes that solutions often need to be tailored to particular locations, however as a large company with operations across the United States, Icon is also looking for solutions that are transferable and replicable in other communities

In sum, select a “community of choice” that you know well, is specific and where you can model solutions that can be shared nationally.

**Success Criteria for Proposed Solutions:**

**Financial** – This is foundational. What is the total cost of your proposed solution? Where will the funding come from to pay for it?

**Social** **Impact –** How does the solution measurably improve the lives of people facing homelessness? How many people are likely to be positively impacted and over what time?

**Environmental responsibility** – How does the solution either reduce negative impacts (waste, pollution) or create positive impacts (restored land/soil, protected water quality)?

**Feasibility** – How realistic is your proposed solution? What are the recommended steps for implementation and are they feasible? Provide evidence of a well-thought-out implementation plan.

**Innovation & Partnerships** – Is your solution original and ambitious? No community can address the housing crisis alone. It must partner effectively with nonprofits, churches, alumni, faculty, staff, donors, businesses, and others. How does your solution leverage the power of partnerships? 

**Risks & Mitigation** - What are the risks associated with your solution and what mitigation steps can be put in place? In other words, what might go wrong in your solution? What assumptions are you making that might turn out to be incorrect? What are possible unintended consequences? Identify these risks and how they can be avoided or at least mitigated. Don’t skip this step or treat it too lightly!

**Key Dates:**

TBD: Power Hour: Expert Panel Q&A – 9:00 am EST

March 1st: Initial Submission Due – 11:59 pm EST

March 15th: Finalist Announced – 5:00 pm EST

April 1st: Finals

**Deliverables**

**Round 1 Deliverables: Initial Submissions Due March 1st at 11:59pm**

1. **The video presentations are no more than 15 minutes long. Everyone must be a part of the presentation. Late submissions will not be reviewed.**
2. **PowerPoint for a 15-Minute Presentation. Your team also must submit a PPT, and a PDF version of the PowerPoint used in your presentation.**

* The review process is anonymous; DO NOT include team member names or photos in the video or in the PowerPoint.
* Intro Slide: Make Up a Team Name and Put It on Your Title Slide (not team member names, just the overall team’s name)
* There is no required minimum or maximum number of slides; it is up to your team to determine the appropriate number of slides for a 15-minute presentation.
* You may include an appendix for additional data, graphs, analysis, sources, etc.

**Finals Deliverables (if your team is chosen as a finalist): Presentations on April 5th**

1. **15 Minute Live Presentation** (Expectation is Every Group Member Must Present)
2. **10 Minutes of Q&A with Judges**

If you have questions, please contact us at [smealsustainability@psu.edu](mailto:smealsustainability@psu.edu )

**Further Reading**

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