

+You: 3D-printed homes: New trend or lasting solution?

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Miriam Axel-Lute: Hello, everyone, and welcome to Habitat for Humanity's 3-D Printed Homes: A New Trend or Lasting Solution. I'm Miriam Axel-Lute, CEO and Editor in Chief of Shelterforce, a national publication for people working in community development and on housing justice. I'm pleased to be with you today to explore the rise in 3-D printed homes and the challenges this new technology faces in various markets and resource settings around the world. From Virginia to India, there's no denying that 3-D printing technology is making a splash in the construction sector, the development community, and among the public more broadly. This is a discussion that will kick off a series on innovations in housing where experts will gather periodically to examine alternative construction materials, sustainable solutions, and outside-the-box approaches around the world. And now I'd like to turn first to a short video that shows a 3-D printed home throughout construction and to completion. And this is the first 3-D printed home produced by Habitat for Humanity in the United States.

[Video playing 0:01:16 to 0:03:24]

Miriam Axel-Lute: Great. And now I'd like to turn to our esteemed panel. Thank you all for being here today. Ryan Colker is the Vice President of Innovation at International Code Council, the leading global source of building standards and safety solutions. In this capacity, he works to identify emerging issues in the building industry, including how new technologies can be leveraged by codes and standards and methods to modernize the application of building regulations. Janet V. Green is the CEO of Habitat for Humanity Peninsula and Greater Williamsburg in Virginia. Since its founding in 1985, this organization has built, renovated, and repaired more than 500 homes. Janet came to Habitat in 2002 following 20-plus years in Washington, DC.

And Adithya Jain is cofounder and CEO of the startup Tvasta Manufacturing Solutions, which develops 3-D printed solutions, construction from 3-D printed houses to toilets and other structures. In 2018, Tvasta won best startup of the year in construction from Construction Industry Development Council and best startup of the year award from the Technology Development Board. Welcome all of you. Thank you for joining us, and thanks as well to our audience today. Just a note the panel will be taking questions directly from the audience later in the hour, so please drop your comments and questions in the chat box as we go. So Janet, we'd like to start with you. We just saw a peek inside the construction process for Habitat for Humanity Peninsula and Greater Williamsburg's 3-D printed home. Now, when most people in the US think about Habitat, we typically think about volunteer-led builds using more traditional methods, so can you tell us what attracted your affiliate to this new building approach and how, based on your experience of doing it, it might fit into the future of both Habitat's work and home construction in general?

[0:05:32]

Janet Green:

Well, thank you, and I hope you all enjoyed the video. I have seen it countless times, and it still gives me goosebumps. I like to think of 3-D printing Habitat homes as a new tool in our toolbox. So we still did use volunteers on this home after the 3-D portion of the exterior of the home was printed. We did the interior similar to most Habitat stick build homes, so we did have volunteers, and it is just an exciting new time to try to figure out this new technology. 3-D printed homes are more energy efficient. They are also temperature and better for heating and cooling costs, so that will be great for our longtime homeowners. Concrete is more resistant to tornado damage and hurricane, and concrete doesn't burn, so whether you're in Arizona where they also just finished their 3-D house and it's awfully hot there, or in Virginia, or in India, I think this new technology can really be transformational for both Habitat and other nonprofit and for-profit developers.

[0:07:00]

Miriam Axel-Lute:

Great. Thank you, Janet. And so as you mentioned, 3-D printing is gaining traction not just in the US but around the world, so I wanna turn to Adithya next. You cofounded Tvasta while you were in university, and it's the first startup in India to focus on 3-D printed homes. Can you tell us a little bit more about the technology and what makes it a good fit for tackling affordable housing in India?

[0:07:26]

Adithya Jain:

Absolutely. So I started this company along with my team, my co-founders, about five years back, and what attracted us toward 3-D printing was that it is a completely digitized method of construction, and we could use this to tailor make structures for individuals in India and as well a house is the biggest asset that a person invests in their lifetime, and in almost all cases, they want it customized, they want it tailor made for their requirements. And this is extremely important to them with respect to their daily life and also with respect to their ambitions. And hence, with 3-D printing, which basically involves a digital method of construction where we have a 3-D printer which deposits materials in a particular shape and form that the user requires, we can provide this customization without sacrificing productivity to the end customer. And this can really be a game changer in India's construction industry where almost 90 percent of home ownership or home construction is directly met by the individual hiring a small contractor to build their house.

And what happens in these cases is that there is very minimal modern technology-based intervention that actually is used. It's conventional construction which has been practiced for the last 50 to 60 years that is currently being used and in this particular space. And this is not productive on the ground. There are a lot of inefficiencies, and 3-D printing can really change that. And another aspect is we – with 3-D printing, we are able to pass on the benefits of economies of scale to the end customer without sacrificing productivity, and that can be a game changer anywhere.

[0:09:27]

Miriam Axel-Lute:

Great. Thank you, Adithya. I wanted to follow up on that. So we've heard from you and Janet about some of the benefits, but we know this is a fairly new technology, and so can you tell me at the moment what are some of the biggest limitations of the technology and do you think they can be addressed?

[0:09:45]

Adithya Jain:

Absolutely. I think 3-D printing has a multiple. It's not a technology that's a monolith. It has multiple elements to it. You have a 3-D printer itself which is the machine. You have the material or the concrete, which is extremely important, and this is a specialized form of concrete that we use for 3-D printing. It's very similar to conventional concrete, has all the properties of

it, but you require it in a specific form. And you have a software that manages the 3-D printing process. And you have to of course marry this technology with conventional civil engineering. So all of these aspects have to come together for 3-D printing to really work on the ground, and scaling it up with all of these various elements working in cohesion is a very big task. So I would say logistics is a major constraint with respect to scaling up 3-D printing at this point of time. Another aspect is execution capacity of any organization which is doing this because you require a fair bit of training to be adept at 3-D printing technology and really executing things on the ground. Another key aspect in certain geographies could be customer acceptability. We have seen in India that customers are really keen to adapt 3-D printing in fact because people see that it is similar to a conventional house, made out of concrete, which is a very familiar material to house owners in India, so there is a fair bit of positivity towards 3-D printing in this country, but that might not be the case elsewhere. So these might be a few factors that might hold up the advance of 3-D printing.

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Miriam Axel-Lute: Got it. Thank you. So moving to Ryan, we place a lot of trust in our homes and our other infrastructure to keep us safe and secure, and we have that confidence in part because of material and construction standards that guide the sector. Ryan, what considerations to regulators weigh when it comes to standards for new technologies like 3-D printing? How do you look to find a balance between promoting innovation and still preserving that building safety and quality?

[0:11:52]

Ryan Colker: Yeah, and thanks for the question, the opportunity to participate today. You know, at the end of the day, regulations and standards are really intended to provide a uniform level of safety, sustainability and resilience for building occupants, building owners. And so really what the regulatory community is looking for is new technologies to meet similar levels of requirements. And so with new technologies, there's certainly questions on whether they can meet the resilience and sustainability and efficiency and safety goals. And so really it's about sort of testing those products, having the opportunity to sort of see them in the field, make sure that they do meet those specific requirements around safety and sustainability. And so there are tools within the regulatory landscape to be able to accomplish that, so there are things like product evaluation, which really go through that testing process and provide some level of assurance to folks on the ground that the materials and technologies being used do

meet those requirements. And so sort of figuring out that balance is essential, but having new innovations and new practices in the industry is really what's going to help drive meeting the sustainability, resilience goals that folks may have.

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Miriam Axel-Lute: Great. And, Ryan, we have a follow-up just for you from the audience. For ICC, what building classification type does 3-D printing construction fall under?

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Ryan Colker: Yeah, so 3-D printing is, at this point, primarily used in the residential space. We do have an acceptance criteria for use in multifamily as well. So there's criteria within the international residential code for how to use 3-D printed technologies, and then we also have a product evaluation for the cement printing material. And so really providing some level of assurance that that material provides similar qualities to what you would expect from other forms of building enclosures.

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Miriam Axel-Lute: Great. Thank you. I wanted to follow up with Janet because something Adithya mentioned about acceptance and reaction in the community. So, Janet, when your team introduced the idea of a 3-D printed home, what was the reaction from your local community broadly and the family that moved in?

[0:14:33]

Janet Green: Let's start with the reaction of our construction crew.

[0:14:38]

Miriam Axel-Lute: Oh, that's important too.

[0:14:40]

Janet Green: They were just as flummoxed as everyone else about what this means. Our longtime volunteers were also curious. But I think that we all were very open to what this might mean, and mostly can we provide more affordable housing for these families with low to moderate income? Can we do it cheaper? Can we do it faster? Can we scale? And so from the

community's perspective, I think they were curious. I want to urge people who are thinking of this, as always, as Ryan just said, work with your permitting and codes because they're the key to making this all work.

As far as our homeowner, she was actually picked a full year ago as so many Habitat families do when they have to work on their financial literacy and their education classes and their sweat equity. So when it came time that she was matched, she didn't understand this either, but she stated very proudly that she grew up in her grandparents' home that had concrete, and she thought it was cold, and that was one of her biggest concerns was would this be cold. And we are so proud that she got to watch it from very beginning to the end, as most of the Habitat homeowners do when they're working on their sweat equity, and could help make some of those changes that would make her happier with the actual completed project of her Habitat home.

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Miriam Axel-Lute: Great. Thank you. And so, Janet, you mentioned cost, and the promise that many people talk about with alternative construction methods is that they will be more affordable as we're struggling with housing costs around the world. And at Shelterforce, we did a special series last fall called Building Differently, and when we spoke to various nonprofit developers who were experimenting or looking into these different methods, for the most part for them, the cost savings weren't quite there yet. It was too new. So what – did you achieve any savings and, more importantly, what will it take from your experience in terms of infrastructure and critical mass to realize the projected cost savings, and how large might they be?

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Janet Green: Good question, and we did not realize any cost savings, but that was due to that this was brand-new technology, and being the first Habitat completed 3-D printed home in the nation, we had a lot of stops and starts. When we finally started the actual printing, it was August here in Virginia, and it got to be over 100 degrees, which is nothing compared to Phoenix, Arizona, but the concrete and humidity did not like each other. They were not compatible. We did a lot of testing and a lot of prototypes, which costs money, and we were very fortunate to have a lot of wonderful sponsors and donors and interested parties, but it was not cheaper. It was faster if we could have kept printing continuously. So it took us about 28 hours to print the 156 layers of concrete that you saw there from the video. Had we been able to do more than one house, I think the cost savings would have been substantial, and that's where we're hoping that

this new technology, as we move forward, can be printing more and more houses. It should be cheaper, cost less, be safer, and we look forward to those improvements in the future.

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Miriam Axel-Lute: Adithya, I'd like you to get to weigh in too on this question of cost savings from your experience.

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Adithya Jain: Absolutely. So 3-D printing is a completely new technology in the market, and it is being experimented currently in the I would say pilot scale in various geographies. So when we do bring in a new technology, there is training required, there is a lot of testing required. You need a demonstration to be done to customers in some cases. So all these things do add to the cost. So cost savings will only be realized over a period of time. I think this is the key scenario for any new technology that comes into a market, and construction is a very capital-intensive industry, and hence it would take a bit of time, but as Janet said, I think we would be able to see cost savings when we construct multiple structures in parallel in the country. And I think with a little bit of scale, we will be able to pass on a real cost savings to the final customers irrespective of geography and irrespective of the types of structures that we are doing. So I think that minimum bit of scale is absolutely necessary, and that's something that 3-D printing is just getting to.

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Miriam Axel-Lute: All right. Thank you. And so we've also heard a fair amount about the concrete and some of the benefits of using concrete and this special blend, but can you talk a little bit about the environmental impact of concrete more broadly and the sustainability of this technology because we know that sustainability and environmental impact are not just in the energy efficiency of the home that you've created but the effects of the materials that you're using and all the energy going into construction and maintenance and for the life cycle of the home. So how are you thinking about that? I'll start with Adithya, but anyone else can jump in to talk about the materials.

[0:20:48]

Adithya Jain: Sure. Absolutely. I think you raise a very important point. So there are two aspects to sustainability. There is the energy consumed by the structure

during its lifetime, and you also have to look at the construction process and how much energy and carbon footprint is generated by these processes. Concrete is certainly not the ideal material for us in the long term since it is, I mean, not extremely sustainable from that perspective. We are looking at alternative materials such as geopolymers which can have a negative carbon effect where we will be using industrial waste and other materials for the construction process. So these – when we transition to this 3-D printing as a process will become more sustainable, but currently concrete is the most stable material that we can use, and hence we are going with it.

3-D printing at this point of time can contribute significantly in terms of reduction in energy use over the lifetime of the building. So from that perspective, it can be significantly better than a conventional structure and can contribute positively toward sustainability. But in terms of construction process, I think the technology has quite a lot of distance to go. Alternative materials is certainly one aspect. The second aspect will be localization of the 3-D printing process. You do not want materials to be transported hundreds of miles to be made available for 3-D printing. That contributes to greenhouse gas emissions. You also do not want a 3-D printer itself to be moved across long distances. That also can be unsustainable in the long run. So these are aspects that have to be looked at, and when the technology scales up a little, a larger degree, I think these issues will start getting addressed.

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Ryan Colker:

I think one – one other – one other thing I would add is, you know, with the 3-D printing process, you have less waste on the job site. Every piece of material that goes through the printer has a dedicated purpose, whereas in many job sites we see dumpsters filled of waste materials. And so I think looking at 3-D printing and other offsite construction solutions, you can really address some of the construction waste issue as well.

[0:23:18]

Miriam Axel-Lute:

That's a good additional point, Ryan. And also while we're on your perspective on this, from the ICC's perspective, is there anything that you can do that how regulations can support and encourage moving toward sustainability or sustainable applications of technology?

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Ryan Colker: Yeah. So we actually have a lot of activities in the work currently. One is certainly looking at our International Energy Conservation Code, which regulates the energy use within buildings. We saw from the 2018 edition to the 2021 edition a 9.4 percent improvement in energy savings and about an 8.5 percent improvement in greenhouse gas reductions. So that's certainly looking at the operational side. Looking at the embodied carbon in the construction process and the materials used, we're actually getting underway a standard development process to look at how do we provide a consistent basis for the measurement and verification of carbon across the entire life cycle of the building. So when we talk about say the concrete that's used in 3-D printing, the material itself may have a larger level of carbon in that process, but as both of our other speakers mentioned, there are energy efficiency improvements that come along with that as well. And so how do you sort of figure out the balance between those two and find sort of the ideal strategy to address the really greenhouse gas reduction goals that folks may have.

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Miriam Axel-Lute: That sounds like a challenging – go ahead, Janet.

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Janet Green: Thanks. We partnered with Virginia Tech Center for Housing Research on this home, and they have installed – it was called Raspberry, probably now it's called Building Data Lite monitoring system, and this is a scalable system that is in the home right now, that is collecting data through sensors. They're about the size of a credit card, and there are six of them through the house, and it's going to do everything from tracking and maintaining the indoor environment and air quality, temperature, humidity, flames, gases, and it is sending this information every day. The homeowner doesn't have to do anything to Virginia Tech Center for Housing Research. So we can monitor this home over the life of the home and share this information with everybody on this new technology because we want to make sure it does do what we're saying and trying to be friendlier for the environment. So we're hoping that the BDL system will help all of us improve this technology.

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Miriam Axel-Lute: That sounds really helpful in figuring this out. I'd like to – you mentioned the printers themselves. Adithya had talked about having to move them from place to place, and one of the things that came up in our series is the size of the printer and needing a certain site layout and space around

the building that you're creating in order to use the printer. Does this limit its use in in-fill and are there regions or other things like the humidity that you mentioned, are there regions or settings where 3-D homes are going to work better or less? Start with Janet, but anyone can take the question.

[0:26:58]

Janet Green:

We had a double-wide lot, so that worked well, but I would call it an in-fill lot. But as I mentioned at the outset, I don't think one-offs, printing one 3-D house at a time is ever going to be cost effective. So if you can print multiples, I think at that point, that's where the efficiencies come in. This home was a one-story, 1,200-square-foot, three-bedroom, two-bathroom home, but 3-D printers already have changed that you can do duplexes, you can do four stories, you can do – it's really just the machine and the size. So I don't think it's going to be a challenge to where you're going to build, but again, it's the more you can do multiples with those cost efficiencies because, as we talked about, trailering in the printer, having the different cranes, et cetera, to move this heavy equipment, to just do one home it is not cost effective.

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Adithya Jain:

Just adding a point to that, I think there are multiple possibilities with 3-D printing. What was explained in the video was what we call onsite 3-D printer where the 3-D printer itself goes to the final construction site and carries out construction. That is of course one way of doing it, and it is a very relevant way of doing it as well, but there is offsite 3-D printing as well that is used by several players across the world. We use it in India, and we feel it is a very valid technology for especially urban construction where we 3-D print modules or elements within a factory environment and then get them assembled at a construction site. This especially in crowded urban environments. Since it's what we have in India, can be extremely cost effective, and we can have structures which are very customized one-offs done without sacrificing productivity. So I think the size of the printer need not be a constraint if we look for other types of printing systems, offsite construction system is one where we're not limited by the size of the printer. We also have certain 3-D printers which function based on robotic arms and not a large gantry system, so these are more robotic arms which are based on – I mean, mounted on vehicles which can move around. So the size of the printer need not be a constraint.

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Ryan Colker: Yeah, and I would add to that. I mean, certainly in the offsite construction space, we're also seeing an increase in 3-D printing in factories, not just with cement-based materials but also metal-based materials. And so you can develop full volumetric modules, put them on the back of a truck, and move it to the job site. And so using 3-D printing technology in offsite applications I think is another area which could address some of the challenges that both our other speakers mentioned.

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Miriam Axel-Lute: That's really fascinating. I had not heard of offsite and 3-D printing together, although it makes so much sense. Question for Ryan. So as this is new and many local governments haven't seen it before, it seems important to engage with local governments before a 3-D printing project begins. What would you say is sort of the transition strategy at the local level with people doing permitting and planning to help them understand moving from thinking about a traditional site build to 3-D?

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Ryan Colker: Yeah. I mean, certainly seeing projects like the one in Virginia is certainly a good start and sort of provides at least some perspective on others have done this before. But for folks who are considering using 3-D printing, as Janet mentioned, I think your first stop is probably your local building department. Talk to them, understand sort of what their initial concerns are, and they should really be partners throughout the entire process. So that's certainly essential when you're talking about a new project. Sort of overall within the code official world, education and training is certainly key. Looking at things like the appendix within the International Residential Code is a really good start, but really having things like product evaluations, which folks are familiar with, that really provide the basis for use of new materials and technologies is essential, but really having that education and training access to particular projects and, you know, I saw within the video multiple different folks from the community being able to sort of walk through the house once it was completed. So those sorts of things are really important. We'll continue to see evolutions within the context of the codes that as well will really help advance these types of technologies.

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Miriam Axel-Lute: That's great. Janet and Adithya, how did you work with local and even regional or national governments are relevant when you were developing your projects? I want to start with Janet.

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Janet Green: We started right away. when we were first approached about this, the initial call actually came from James City County, which is where Williamsburg is located, and that was the very first phone call to permitting and codes to make sure because we had heard from the Arizona experience that that is what has taken the longest period of time. So we were true partners with them to work to make sure that this would all be done according to codes, according to permitting, and to make sure we could answer as many questions as we possibly could.

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Adithya Jain: So we started working primarily with the local government to get our plans approved and to get started on the construction activity. We of course had to work with structural engineers to ensure that the structure that we are designing is safe, and this is one of the first structures to be constructed in the country using 3-D printing and hence there was a lot of education that we had to sort of impart to structural engineers who had not seen this process before. So they of course come from a safety-first perspective. So there was a lot of convincing that we had to do, but apart from that, the central government has been extremely supportive of the technology and the initiative that we have taken, and the government of India has a special part for approving new technologies in the country. Since the codifying process usually takes a longer period of time, they enable a different part so that technology led processes can get into the market quicker. We are part of that process, and they have been extremely supportive. So they ensure that certain protocols are followed during the construction process so that safety is maintained, but at the same time, a certain level of understanding is imparted to structural engineers and other consultants who have to work with this technology to ensure that the technology gets into the market quickly. So the governments have been extremely supportive in this case, but we have to sort of work with them very closely to make it happen.

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Miriam Axel-Lute: Great. So we have a lot of great questions from the audience. We want to make sure to make time for them, so we're going to jump in now. And the first one, which is a big question that comes up so we devoted one of our articles in our series to this question is housing construction generates a lot of jobs in the US and around the world, and to some extent sometimes the cost savings of these alternative construction methods is because

they require less labor. So how are you first just sort of grappling with that question, and second, how are you incorporating local employment into these projects? What kind of skilled labor and training do the projects require?

[0:35:29]

Janet Green:

I'll go first. I'm a member of the Virginia Association of Homebuilders, and that was the very first questions that we got. Aren't you taking away jobs? This was happening also during the pandemic, and everybody I know is struggling with finding employees. We didn't want to take away any jobs, and especially with Habitat, when we use a lot of volunteers, but we still needed all of the licensed stuff, so HVAC, electrical, plumbing, and we still had all of those subs in there. We are also now working with the local community colleges on developing a 3-D printed class, curriculum because a lot of younger people don't want to go into the construction trades, but they are very good with technology and computers. So we think that trying to marry these two is that we need more people to want to be involved in the construction trade, and teaching them the skills with 3-D. So we're coming up, like I mentioned, with a curriculum with the local colleges to try to teach students this new technology. But we are not trying to take away any labor, and I don't see that happening in the foreseeable future with 3-D technologies.

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Ryan Colker:

Yeah, just building off of what Janet said, one of the things that we're seeing across the country, at least in the US is that the availability of construction labor is severely limited. And so looking at opportunities to address those labor shortages through things like 3-D printing and offsite construction is certainly a viable strategy. And I think really sort of building off the coolness of the technology and attracting new folks into the workforce, maybe folks that haven't traditionally thought of construction as a viable career, you know, things like 3-D printing, building information modeling, and some of the software tools that are used to support it I think is really exciting.

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Adithya Jain:

So I think especially in India, you have so much construction currently going on that the opportunity for building new structures is almost unlimited. The amount of migration that is happening from rural parts of the country to the urban part of India is so huge that you would require almost 10 million houses in the next two- to three-year timeframe for

these shortages to be sort of accommodated with. And India's going to see an urban boom that we currently have 300 million people living in urban areas, becoming 600 million by 2030. And construction is a sector where we do not have enough capacity to deliver the number of houses that are required to accommodate all these people who are moving to urban areas. So I don't think it is taking away jobs. It is certainly creating a level of productivity and opportunity whereby we can provide a very essential service. So I think when looked at it from that perspective, it as an absolute need for the country at this point of time. And also construction is a sector where labor productivity is one of the lowest compared to other manufacturing processes, so I think a technology like 3-D printing with a certain level of automation would be very welcome in terms of how it can improve the productivity of the entire labor force.

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Miriam Axel-Lute: Great. Now, with any new technology, one of the benchmarks for success is the potential to improve upon the norm set by existing methods, and we've heard a little bit. You guys have all mentioned something about the improved performance of 3-D homes, but I think the audience would like to hear a little more both in terms of comfort and energy efficiency and disaster resilience. Can you tell us a little bit more about how they compare to conventional homes? Let me start with Ryan.

[0:40:04]

Ryan Colker: Yeah, I mean, I think at the end of the day, we're looking at a new technology that has the potential to advance energy efficiency improvements and disaster resilience. I think if we think about sort of concrete structures, their ability to withstand wind and wind-borne debris in storms I think is certainly proven out. I think there's also an opportunity to think about sort of the performance or the opportunity to develop 3-D structures after a disaster event when housing stock may become very limited. The ability to produce robust structures after a disaster event could really be an opportunity for the 3-D printing sector.

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Adithya Jain: Absolutely. I –

Janet Green: I would love – go on Adithya.

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Janet Green: That's where I would love. Instead, when you got these horrible earthquakes and hurricanes like what happened in Haiti, wouldn't it be wonderful instead of getting temporary shelters that are not going to last very long to be able to go in and do 3-D permanent shelters which would last longer and be more permanent for these residents in these disaster areas? I mean, that's where I would love to see this new technology really take off.

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Adithya Jain: Absolutely. So in terms of alleviating sort of impoverishment that comes after disasters, 3-D printing can really contribute because it's a methodology of construction that can deliver rapid sort of structures – structures in a rapid manner. But apart from that, 3-D printing can also be very effective in delivering a disaster-resilient structures, especially in the case of hurricanes. We can have structures which are tailor made or designed in such a manner that they are much more sort of resistant and also not sort of undertake the same level of sheer strength of force during a hurricane. So this has been experimented with in the eastern coast of India, not with 3-D printing, but other traditional materials of construction that is a specific design that are more resilient towards hurricanes. Unfortunately, with conventional construction practices, these kind of structures, designing them becomes very difficult. With 3-D printing it's very easy, and it is really something that we want to try out on the eastern coast of India, which is really susceptible to hurricanes. So disaster-resilient construction is something that gets very little attention but that's something that 3-D printing can really contribute.

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Miriam Axel-Lute: That's great. Quick follow-up. Janet had mentioned permanent and long-lasting, so what is the estimated life of a 3-D printed exterior of a home? Is it different from traditional construction?

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Janet Green: No one really knows yet, but we're not anticipating it being any different. The homeowner, as all Habitat affiliates know, has closed on the home and signed a 30-year no-interest mortgage. But as I mentioned earlier, we are monitoring this. We are sharing the information to make sure that this homeowner family can live there safely and securely. And we do know her first electric bill was quite less than when she was renting from an apartment. And when the weather gets warmer here in Virginia, we are

hoping to – we are planning on installing solar panels for even more energy efficiency of this home.

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Ryan Colker: I think one other thing to think about relative to durability is sort of with the concrete walls you won't have susceptibility to termites or other pests. And then you also sure don't have some of the challenges of water infiltration which could lead to things like mold and other things. So certainly some durability benefits from that type of process.

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Adithya Jain: Certainly. I think with standardization of the entire construction process that is possible with 3-D printing, we can expect better durability. But as Janet rightly said, we do not know yet. All we can do currently is accelerated testing within certain laboratories, and that gives an estimate but not the authoritative figure that we can put out in the market at this point in time. But we do not estimate it to be any less than commercial construction, and in most cases, I think we can confidently say that it will be better.

[0:45:00]

Miriam Axel-Lute: Great. So are there certain regions or settings where you expect 3-D printed homes to be more or less accessible for families? And are there potential issues of access and site level constraints that you can solve with this technology? And perhaps Adithya could start on this one.

[0:45:27]

Adithya Jain: So I think that's a very relevant question, and in India you have areas that you have extremely crowded environments in urban settings in India where you require multistory construction going up to 20, 30 floors for housing to be really viable. So I would say at this point in time, 3-D printing has not reached a level where we can sort of cater to these requirements. We cannot at this point in time construct structures which are 20 or 30 stories tall. Maybe go a few floors, but not more than that. So in those urban segments, 3-D printing will not be able to make a dent for a while. In semi-rural settings or semi-urban settings, I think 3-D printing can really make a difference. Individual homes is where I think 3-D printing can really shine at this point of time, delivering it with a certain level of quality and with a certain level of affordability I think can be done

with 3-D printing quite well. So that distinction will be there in the market for a while.

[0:46:36]

Miriam Axel-Lute: That's great. And are there any weather constraints? Janet had mentioned the humidity affecting their build in August, so is there limits in terms of times of year or climates that affect the outcome?

[0:46:56]

Adithya Jain: Certainly. I think in India the climate is a little more stable than what it is elsewhere. So we do not have that level of variability in most parts of the country, but weather certainly affects the construction process. I mean, in certain extreme conditions or certain remote parts of India where the temperature goes sub-zero, I mean, concrete does face a challenge there. So certainly 3-D printing will have to sort of come up with methods to adapt itself to constructing in extreme high temperature that is 50 degrees or more kind of scenarios, and at the same time, sub-zero temperatures is something that the technology will have to adapt to. So at this point of time, there are no answers to these questions from 3-D printing.

[0:47:53]

Miriam Axel-Lute: Great. We had a – oh, go ahead, Janet.

[0:47:58]

Janet Green: I'm sorry. I just – when you're asking where, we partnered with Alquist 3-D on this that they were founded to build more affordable housing in distressed communities, primarily rural. And so I know that that is a goal for all of us, either low-income urban areas or rural areas. And so I think we are learning literally every day how this technology can be adapted and where it can be used. When we had the initial print, as I mentioned, it was 110 degrees humidity, and when we had the dedication ceremony, it was about 30 degrees. So we've had all of those extremes, and we're learning every day, but I think this technology can easily be adapted. This machine, the COBOD, construction of building on demand, came from Denmark. So we are learning every day about what this technology – where this technology can best be used.

[0:49:06]

Miriam Axel-Lute: Great. And so jumping off of that, what kind of sector ecosystem does one need to make 3-D printing really successful? And I start with Adithya, and maybe an add to that, can you speak to the support that innovators like your company need in order to continue to develop and test this technology?

[0:49:34]

Adithya Jain: Absolutely. So I think there are several things that have to come together to make technology like 3-D printing succeed in the market. So when we started, we had to work on all these aspects from scratch, which is machine building capability, material development capability, software development, marrying the entire 3-D printing process with civil engineering. These are things that we had to work on, and hence an ecosystem is absolutely necessary from a machine building perspective, logistics of materials and delivery on the ground, ensuring that structural engineers understand what 3-D building is all about and how to sort of approve structures for construction on the ground. There are several aspects that have to come together. Consultants in the construction industry play a huge role, especially in India, and I think a lot of training and handbooks have to be handed out for them to really understand what this technology is. So there is a lot of effort needed from both the regulatory side and the – and companies like us who are original equipment manufacturers to sort of train other industry folks to sort of adopt this technology.

But apart from that, it does require a lot of support to sort of bring this technology to the market. Government has to sort of support us from a regulatory standpoint, and that has been done in India. We also require support from incubators and accelerators, and we were lucky to have Habitat's ShelterTech Accelerator supporting us from really early on, I think from 2017 onwards. And Habitat has also supported us with catalytic funding and also being an investor in our company I think has been really sort of a great experience to work with Habitat. But apart from that, we also learned a lot about customer mindset and what customers will accept and won't accept from experienced organizations like Habitat for Humanity, especially since you have constructed more than 100,000 homes across various parts of India and also Asia. You exactly know what customers require. So these kind of elements are really necessary to push innovation such as this to the market and to the next level.

[0:52:05]

Ryan Colker: And I would build off of that of the importance of having the regulatory community involved from the very beginning, being supportive, really understanding sort of what the technology is, what it can deliver, and so having codes and standards and code officials that really embrace the technology and really sort of be supportive of its use in communities. You know, at the end of the day, communities are looking to address a whole host of problems, and so having technologies that are approved and can really help deliver on those goals is really essential.

[0:52:44]

Miriam Axel-Lute: Great. So we're coming up toward the end here. I have a final question from the audience which I'm hoping everybody can address pretty briefly. Where do you see the technology – this technology evolving in the future with respect to both housing and other infrastructure projects?

[0:53:03]

Janet Green: I'll start. We need everything we can to build more affordable housing, and if this is, as I mentioned at the outset, if this is another tool in the toolbox, let's continue to keep building more affordable housing.

[0:53:20]

Adithya Jain: Absolutely. I think 3-D printing will be a technology that will be really sort of friendly towards individual house owners who require safe and reliable technologies for them to have their dream homes. So I think it will really contribute towards people having good quality housing that are customized towards their needs rather than having some design or technology being imposed upon them from – depending on external realities. So I think 3-D printing will really make a dent in the construction market moving forward and will be a scalable technology.

[0:54:04]

Ryan Colker: Yeah, and I think from my perspective, the disaster recovery opportunity is certainly fascinating and one thing that we can see moving forward in the future. I think the other is taking the sort of onsite lessons learned and leveraging that technology within the offsite construction industry, and so not just applying it to maybe full builds but thinking about sort of how do we improve housing overall.

[0:54:34]

Miriam Axel-Lute: Thank you. So as we close, I want to quickly go around the panel again with this. What is one word or phrase that comes to mind as you look to the future of 3-D printed homes? Let's start with Janet.

[0:54:48]

Janet Green: I'd say innovation.

[0:54:52]

Ryan Colker: I'd say exciting.

[0:54:58]

Adithya Jain: I'd call it a dream home.

[0:55:00]

Miriam Axel-Lute: All right. Thank you. So on behalf of Habitat for Humanity and Shelterforce and all our panelists, I want to thank all our guests for joining us today. I've enjoyed this conversation. I've learned a lot, and I'm sure that you have as well. So please stay tuned for more from Habitat for Humanity on subjects like this.