Paul Teson: Sometimes called 3D printing, additive manufacturing is on the cutting edge of technological advancements in building construction. To create a structure, builders start with digital designs, and then deploy large-scale industrial 3D printers and locally sourced materials to create [00:00:30] structures, layer upon layer until the model is completed. Just one exciting use case of this technology is being leveraged by NASA and Jacobs to create habitable structures on the moon and Mars using lunar and martian regolith as part of the next slate of interstellar missions. Now we're seeing growing momentum to put this technology to work for building needs here on earth.

Hello, I'm your host, Paul Teson, and in this episode of If When we explore additive manufacturing with Dr. Patrick Sermon, [00:01:00] department head and associate Professor Charles Dewey McMullen, chair in construction science at Texas A&M University, and Kurt Maldovan, Jacob's global director digital delivery solutions. Patrick and Kurt, thank you both so much for joining today. I'm looking forward to talking with you about additive manufacturing. It really is a fascinating development in construction, and I've been learning a little bit about it but I'm really looking forward [00:01:30] to hearing from you more about it and sharing your insights.

So Patrick, to start, and kind of set the table for our listeners, can you tell us what is additive manufacturing and could you describe it for someone who may be new to the technology?

Patrick Sermon: Yeah, definitely. Thanks, Paul. I think the best way to define it is using the ASTM ISO standard 52900, which came out in 2015. And it's easy to see why people [00:02:00] would be confused, because even within the first few sentences of that standard, they say that additive manufacturing is actually three different things. And the thing of those three that people most usually identify with additive manufacturing, is actually the last one, which is additive shaping. Using some kind of a feedstock, maybe extruded plastic filament in a maker bot, 3D printers, probably what a lot of people see these in K through 12, and definitely in our college [00:02:30] of architecture and department of architecture. We have lots of these maker spaces where people can do rapid prototyping.

But really there's also subtractive shaping and formative shaping. So even starting with a large block of something like a CNC machine and extracting things from it until you have the item, that is also considered additive manufacturing. And then that last one would just be adding directed energy or just doing densification or seeming things. But primarily through additive manufacturing, [00:03:00] people usually associate that with 3D printing, or the smaller scale, extruded plastic filament 3D printing.

Paul Teson: It's kind of fascinating. You made me think of that old Michelangelo quote, he saw a block of marble and he just carved until he released the angel within it. So it's kind of interesting, I never thought of additive manufacturing is also something where you're taking raw material and you're chipping away at it until you have a finished product. [00:03:30] So what problems are being addressed by additive manufacturing? How is it uniquely situated to solve for those?

Patrick Sermon: Well, you've got to look at the scale of the additive manufacturing approach that you're using. Leading up to this, I was thinking about really in construction, it's a two or three trillion dollar industry, and you need every single tool in the toolbox in order to make it happen. And it could just be the material that you're using, but [00:04:00] especially for large-scale construction, which I think is primarily what we'll be focusing on today, is typically a cementitious material that is placed in usually layers. Imagine a cake being decorated from the bottom up. This is typically what people think about when they think of 3D printed additively manufactured construction.

And if you look at that workflow and you compare it to the traditional concrete truck and formwork and all of the work that goes into [00:04:30] building the building on the outside, then cast in place concrete for the building, then stripping the formwork, far less labor, far less waste, far quicker, and in an ideal world, much safer, less labor, using people's brains instead of their brawn. And so all the things that we hope to get rid of in the dull, dirty, and dangerous world of construction, it's been described as the panacea. But obviously, as we talk about it here, I think you'll see that it's still [00:05:00] emerging, but it's exciting with the realm of the possibility that it could help solve.

Paul Teson: That's interesting. And I bet there's probably, we may not get much into it today, but I bet there are probably some synergies to be had with generative design as well. So that when you're using additive manufacturing, like you were saying, as far as proper waste management, you're using your resources to the optimal effect, and additive manufacturing is [00:05:30] allowing you to use resources without a bunch of superfluous material.

Kurt Maldovan: I think I see it three different advantages, one or two of you to touch on. But for additive manufacturing, generally speaking, it can be a lower cost. It's faster and it's more sustainable, so the cost savings is derived from using in-situ resources or ISRU, or simply local materials. Then you have the ability to construct more in the same [00:06:00] amount of time, due to automation. And then thirdly, it's also more sustainable due to less waste and using locally sourced materials that you don't need to transport, or it can be less energy intensive in terms of process. And then beyond this, with additive construction, it can be computer-controlled. So the design isn't limited to a simple box, and you can then create a much more organic design, which then has other benefits that we'll touch on a little bit later, I believe.

Paul Teson: Okay. That is fascinating, that [00:06:30] it allows you to use the in-situ resources and that you are properly managing your resources. Are there any challenges, Kurt, to using additive manufacturing that still need to be overcome? Perhaps like structural integrity challenges, building code challenges, anything like that?

Kurt Maldovan: Absolutely. I think Pat mentioned the ASTM standard. But the biggest question that we had internally, when we first started investigating, [00:07:00] is large scale additive construction, additive manufacturing, an area that we could dive into, was related to getting something through code officials and approving authority to say, how can we show that something that's been additively constructed meet specific structural requirements? Will it stand up to the seismic zone, seismic requirements?

And depending upon where you are in the world, where you are in the United States, different code officials [00:07:30] may have a different opinion. We do know that for certain types of construction, maybe a semipermanent type of construction, that there are less restrictions on the types of approvals that need to go into it. Certainly, we want to build something that is safe. And certainly we have people, engineers, if you will, that understand the materials that are going into the additive process, and specifying materials that meet code. But that is a big question. And I think Pat, when we talked previously, you've shared some other anecdote notes related [00:08:00] to review and co challenges.

Patrick Sermon: Yeah, definitely. We have a large center for infrastructure renewal here at Texas A&M. And obviously we have asphalt and concrete experts here at Texas A&M. But one of the things that they identify, is that the whole industry is biased toward concrete production. And construction is so risk-averse, that we don't typically want to use new materials, we don't want to innovate because [00:08:30] we sort of associate innovation with the unknown.

And when it comes to life safety or factor of safety on our buildings, as evidenced by some of the recent disasters in the news, in Mexico with their Metro line, the Florida international, pedestrian bridge of Miami, there are all these challenges that we already know with all the codes and all the reviews that we currently have. There's still a risk. And even one life loss would be catastrophic. Just to get it [00:09:00] to actually work is really challenging. I have seven different challenges that came from a paper that was done by a young, talented captain named Jane Jagoda at the Air Force Institute technology, working with Lieutenant Colonel Andy Hoisington, and she reviewed 3,699 papers.

Kurt Maldovan: Wow.

Patrick Sermon: Yeah. From 1998 to 2018. And she found 281 that really nailed it down, and did a classification of these. And the seven, for the hardcore additive manufacturing people [00:09:30] out there, you've all faced these challenges, but first would be material radiology. That's just basically like the flowability. Then structural integrity, the anti isotropic nature, where it responds differently to forces in different axis. Process scalability, it's kind of a one off linear fashion, even though it could be mass produced. Suitability to adverse environments, but using institute resources, if that can be mastered, there's been a lot of work in that area.

The complete automation of going from a BIM file or [00:10:00] a solid works file, or [inaudible 00:10:01] file or other things is hard to do, although desired. Unknown environmental impacts, that you're still using probably a Portland cement-based material, which we know the challenges of that, creating eight or 9% of the overall CO2 green house gases. And then just really uncertain costs because it hasn't been optimized. And so all of these reasons are keeping it from being widely adopted.

Paul Teson: Now Kurt, you've [00:10:30] spoken before about materiality in the context of additive manufacturing. Can you explain for our audience, what you mean by materiality and its relationship to AM?

Kurt Maldovan: Yeah, so I think of it like baking a cake, you need four main ingredients. You need flour, you need sugar, you need eggs, and you need butter. Or more aligned to construction, like concrete, as was just described, you need cement, aggregate, water and admixtures. And so the materiality [00:11:00] are the materials mix essentially, that you'd use to create a structurally sound end product.

And then Patrick, you talked about the flowability and the other six requirements of being able to have something that can actually be, in the case of what I've seen done, extruded through a nozzle and then placed layer by layer on top of each other so that it doesn't just slump down and turn into a liquid when it's placed, it actually holds [00:11:30] its structure. And then thinking about the ability to self-support. And I believe from, again, other researcher that I've spoken to, that looking at the types of printers that are being used, to think about doing things like I mentioned earlier, that are more organic. So if you have a free-form, multi-axis print head, rather than a very rigid X, Y, Z type printer, you can start experimenting with designs from nature, which in themselves are much [00:12:00] more appropriate for self-supporting structures. And that gets us out at the typical box of creating a box, and thinking about things that are much more avant-garde in terms of architecture.

And so you have to get that mix right. You have to have something that is able to be supportive, but also you have to have the ability to place potentially slide in rebar, use those additional materials that Patrick was talking about to give [00:12:30] you that structural integrity, whether it be a carbon fiber or other type of mesh reinforcement, that you can really create these large, multi-story structures with. Most of the work that I've seen done thus far are single stories, smaller scale, but there are studies that are showing, going beyond that, printing multiple stories, coupling multiple structures together.

Paul Teson: Now Kurt, Jacobs is doing a lot of work with NASA. And so kind of [00:13:00] on that theme of what you were saying about avant-garde construction and in-situ resources, we're trying to assist NASA with building lunar and Martian bases, and the idea of using the lunar regolith, for instance, as building material, and the same thing on Mars. How do you see that work, informing what can be done in the built environment here closer to home?

Kurt Maldovan: Yeah, so much of the work that our Jacob Space Exploration [00:13:30] group has undertaken was related to that materiality that I just spoke of, as well as the printer head itself, and understanding that printer infrastructure, the device that's going to actually extrude and place the materials that were formed up. So I can't speak completely intelligently about what our scientists that are working very closely with the team at NASA are doing, because it is truly material science. And as you can imagine, someone has gone to the moon, extracted [00:14:00] that material, brought it back to the lab, and they're analyzing that material and creating simulated materials that echo the same types of properties for, like you said, both the moon and Mars.

So understanding the way that that performs, and they're doing that and in the lab. But beyond that, how do we expand, right? How do we take it to the terrestrial environment? So there's certainly, I'll call it commercially available products. I think of it just like what you said earlier, Patrick, the maker bots of the world, the [00:14:30] desktop printers, whether it be a 2D inkjet, which then you kind of build on top of it, or a three dimensional type printer that you're printing with some type of material. And so I was pretty naive at the very beginning, and thought that it would be fairly simplistic to scale that up, right? Take a design that you're modeling and push it into one of these large scale devices. There's obviously an art that goes into that. And so understanding from our teams that what those implications are, [00:15:00] and understanding that there are limits, there are bounds of the machines that are available today, but also knowing that there are other ways of constructing meaning using robot arms instead of a very rigid three dimensional X, Y, Z type printer.

Paul Teson: Now, Patrick, earlier you had mentioned Portland cement, and you were talking about that it had some environmental impacts. And I understand that in terrestrial construction, Portland cement's fairly [00:15:30] standard material, but it's also a contributor to CO_2 emissions. So how can additive manufacturing allow us to use other materials that might be more environmentally friendly?

Patrick Sermon: Well, you're still going to have that same recipe that Kurt mentioned earlier. You've got the ostensible gravel and the gravel glue, but the gravel glue doesn't have to be Portland cement. It could be geo polymers. It could be anything that will activate as a binding agent to [00:16:00] bring the material together. And the exciting part about that is if you are tied to your flow, you can actually... the feed stock that you feed into the additive manufacturing into the 3D printing process, you can change that to exactly align with the climatic conditions, the day, the temperature. And so you can highly customize your mixed design to suit the day. So it'll cure faster, cure slower. You can really tune in admixtures to [00:16:30] the level that a chemist would love.

And there's lot of different IP research going into the material methodology, but then also into the mix itself. Those are probably the two biggest areas on this research. If not the space research, which I can get into a little bit more later maybe, the two big areas are the material and then the material methodology. And so the reason why Portland cement is so bad for the environment is that you need an incredible [00:17:00] amount of energy to pull out the limestone to get the material, the [inaudible 00:17:07] that help with the chemical and physical curing of concrete. That's all achieved through loads and loads of jewels input into the clinker and the material that eventually becomes Portland cement.

And because of all that energy, that's what helps activate that process. And so you're going to have to find something else that has as much potential energy as Portland cement. And that's just [00:17:30] very hard to do. It'd be like trying to pour a Coke into your car engine, as opposed to some gasoline, which has been optimized to do the job. Portland cement is human designed and created to optimize that gravel glue job, and it's hard to find a geo polymer that is comparable to Portland cement. But there's been a lot of work out there on things that also exist in the state of Texas, as long as I'm giving Texas a plug. The caliche clays and the types of things that cause a lot of trouble, sometimes if harnessed can be that [00:18:00] process stimulant to help catalyze a process that would be comparable to traditional Portland cement curing.

Paul Teson: Now Kurt, let me ask you, how can additive manufacturing be used as a compliment to traditional construction?

Kurt Maldovan: Oh, good question. And I think to lead into that, we're starting to see much more use of construction robotics on project sites. So everything from the Hadrian X, which was a bricklaying robot, [00:18:30] to Boston Dynamics, who has a robotic dog that roams project sites and is able to help capture project data using 3D laser scanners. I think that's a gateway into larger scale additive manufacturing and additive construction.

And the other thing, where I think it's going in terms of compliment traditional, is that you can look at it as it's not all or nothing. So you don't need to additively [00:19:00] manufacture the entire facility or building. You can start to look at the component scale. And I think that was another recent revelation that we had, is that we could start to look at parts and pieces. Whether it be a piece of a façade, or an interior condition where you do want to use that more avant-garde type approach to designing, and you can use the 3D additive manufacturing as a way to place that material and position it on site. And to our [00:19:30] anecdote before, to really they sculpt something that you would have to have an artisan do that, honing it from a piece of material. And so now we have that ability to use smaller scale, component scale additive manufacturing, to achieve similar results, and maybe even add more art in architecture to what we do and deliver.

Paul Teson: It's interesting. I imagine too, that in some instances anyway, you may also save on time, that it may [00:20:00] be quicker to deploy additive manufacturing in certain instances, than doing something manually that might require a lot more dexterity and skill and more time to bring about. Now, Patrick, I have seen before, in relation to 3D printing, stories about how the military is using 3D printing, I think for basic structures and stuff on base camps and things like that. [00:20:30] Could you talk a little bit about how additive manufacturing is being used in the military built environment, and how is it helping them with their needs?

Patrick Sermon: Yeah, definitely. I just have to have you sign a waiver to strap in for, I'm about to use lots of acronyms. You know how the military is about that. But so the army Corps of engineers, URDC, the engineer research and development center, and the construction engineering and research lab, I think, as you say, [inaudible 00:20:59] [00:21:00] in Illinois, is probably one of the furthest along in this. And Jacobs is no stranger. I think they were also part of this project. They had several projects that it seems like the real nexus or the stimulus of all this activity is in 2015. That's also similarly when they started was 2015.

And some of the things that they've done in conjunction with firms like Jacobs and also Caterpillar, is the automated construction of expeditionary structures experiment, ACES. [00:21:30] And it's kind of like a large bee hut, and a bee hut, if you can imagine, is just like a standard military, one story building that's about the same size as a GP medium tent, which is about 20 feet by 32 feet, approximately those dimensions. But they've done several things. They've done just some guard checks. They've done different ways of doing these, but the part that they've always focused on there were expeditionary.

And so it had to the part that I like is that it had to be easy to use for... in [00:22:00] the military, people move all around all the time. And so you might be coming from a unit that had one piece of equipment, but didn't have another. And so they're challenge that they've done is they're trying to make it a lot more approachable and able for anyone to consume with minimal training. And that's some of the work that's been done in the military. Another one would be Icon has a project they're doing right now at camp swift, which is going to be a three story additive manufactured facility. And if you go to most military installations, those post World [00:22:30] War II, three story facilities, those are kind of our bread and butter. They usually have a central common core entrance at the front middle, and then there's either exterior walkways or exterior staircases.

And Icon is really one of the leaders here in Texas, as well as the world. They're out of Austin. And another thing that Icon is working on, is opposed to the small houses that they've built in the affordable housing communities of Tabasco, Mexico. They know that in order to break into the market, you're going to need [00:23:00] a high end product as well. And so one of the things they're doing is sort of like a stem wall that's 3D printed. So imagine replacing a bottom portion of a house that could be CMU or cast in place, that part would have the design appeal and also the structural stability, but then they can build with traditional means and methods on top of that. But not dissimilar to a multifamily project that you might see with sheer walls built out of CMU, wooden timbers, stick built construction in other areas, and then even metal studs some [00:23:30] place. So we're adding to cast in place, precast or now 3D printed additive manufacturing, as a process and an ability. And so I definitely agree with Kurt, when it doesn't have to be all or nothing.

Paul Teson: My last question for today, for you, Kurt, is where do you see additive manufacturing technology headed in the near future, and what are the potential use cases that loom on the horizon?

Kurt Maldovan: Yeah. So Paul, I have a few answers for that. And Pat, you [00:24:00] touched on it just a second ago, but building on is the fully additive manufacturing community is going that way. I think it's just a matter of time before folks get over those hurdles that we discussed with the materiality, with the code reviews, with being able to print larger types of structures. So that's one, is the additive manufacture communities. And the second one is in a similar vein, but it's tying back to disaster relief. So how can we use this [00:24:30] to rapidly deploy in situations where we need to get people that have been part of any type of natural disaster, back into a habitable facility? And so something like this is certainly more a humanitarian type effort. And especially when you can use those local materials that you're not sending. You're not trying to source concrete, you're able to use things that are local, potentially. And the fact that your designs can be relatively repeatable, [00:25:00] if you want it to, running it through a machine, running it through the computer, producing multiple facilities.

Paul Teson: And Patrick, I've got the same question for you. Where do you see additive manufacturing technology headed in the near future, and what are the potential use cases?

Patrick Sermon: Thanks, Paul. I totally agree with what Kurt said. And also just to add onto that, it exploded in 2015 with interest, and especially with the publishing of the ASTM ISO standard. [00:25:30] And then there was a large scale in city resource utilization at the manufacturing conference held by NASA in 2015, and then also one in Arlington in 2017. And if we're not careful, I mean, we're going to fizzle out on some of the momentum that additive manufacturing has started. And it's just really kind of at the peak of the crest, as far as mass customization or mass adoption. And so, again, [00:26:00] I think you need to look at different options where you can sort of wade into the waters, because I'm just looking at this picture even behind my head, if you look at a traditional slip form paper system, that in essence is really extruding and additively manufacturing concrete, which is used very frequently, especially for DOT projects in the state of Texas, which are essentially long concrete ribbons of rebar cages that are making up our large highway infrastructure.

And so [00:26:30] we need to find the marriage of Gomaco or Caterpillar or a company who can make equipment with processes and products that are standardized enough, and in line with standards, so that we can make it easier to achieve, to hopefully realize all these hopes and wishes that we have for better environmentally sustainable and less crew compliment, higher education and abilities [00:27:00] for the people who are working with the equipment, and just always bigger, better, faster, stronger. And so it has these potential benefits, but they have not been realized yet. And so that's the danger with something like this, is that if it was big in 2017, and right now all we're doing is talking about it in 2021, then we're not going to see it get a large market share.

Paul Teson: Interesting. Well, hopefully that won't happen. It won't go the route of nuclear fusion, which I think has been like decades in [00:27:30] the making. It goes back to the seventies. So in comparison, additive manufacturing is still of course in its early days. And I suspect too that as you combine the power of additive manufacturing with things like generative design and AI, and you're starting to see things like the idea of smart concrete, embedded sensors in concrete and roadways to help with data transference, for like automated vehicles and stuff. I have a feeling [00:28:00] that all this technology's going to cooperate with each other and help push each other further along. So we will see. But well, Patrick and Kurt, I want to thank you both so much for your time today and sharing your insights on additive manufacturing. I really appreciate it. And I'm looking forward to learning more, and seeing how it develops. So thank you.

Patrick Sermon: Thanks so much, Paul.

Kurt Maldovan: Thank you, Paul.