# 3 Takeaways Podcast Transcript
## Lynn Thoman
(https://www.3takeaways.com/)

## Ep 48: Designing the Future With Materials That Sense, Adapt, Heal & Grow: Founder of MIT's Self-Assembly Lab Skylar Tibbits

**INTRO male voice:** Welcome to the 3 Takeaways podcast, which features short, memorable conversations with the world's best thinkers, business leaders, writers, politicians, scientists and other newsmakers. Each episode ends with the 3 key takeaways that person has learned over their lives and their careers. And now, your host, and board member of schools at Harvard, Princeton and Columbia, Lynn Thoman.

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**Lynn Thoman:** Hi, everyone. It's Lynn Thoman, welcome to another episode. Today, I'm excited to be here with Skylar Tibbits. He's the director of MIT's Self-Assembly Lab, and author of the new book, Things Fall Together, on the New Materials Revolution. Human civilization has, in many ways, been defined by advances in material science. For example, material science enabled us to have windows. Before the late 1700s, most homes didn't have windows as glass was very delicate and very expensive. And the discovery of steel, because of its lightness and strength, enabled us to build skyscrapers, which we wouldn't have been able to build, of course, either out of stone or out of brick.

**LT:** To give another example of material science, to build today's smartphone, back in the 1980s, it would have cost about $100 million per smartphone, and each phone would have used about 100 times as much energy as a smartphone today, and be about 50 feet tall. That's the power of advances in materials. Material science combines physics, chemistry and biology. To paraphrase Peter Diamandis, material sciences uses the periodic table as its grocery store, and the laws of physics and biology as its cook book. I'm excited to learn from Skylar what the next advances in materials will bring. Welcome, Skylar, and thanks so much for our conversation today.

**Skylar Tibbits:** Thanks. Pleasure to be here.

**LT:** Skylar, let's talk about some of the exciting new materials and what they will mean. What new properties will materials have?

**0:02:05.4 ST:** I would start by looking at materials in the most macro sense, in the sense that I'm interested in how materials can have agency, and how material properties can emerge through existing materials. So I guess I'm just prefacing that there's lots of people working on the forefront of inventing new materials. What we work on is how do we take existing materials and create new properties with those existing materials, or amplify their properties to create surprising, new, awesome behaviors.

**ST:** In terms of the properties themselves, we're interested in sensing, so how materials can sense different things, and often, materials can sense things that humans and robots can't, or it's very challenging to sense. Different forms of actuation transformation, how materials can move, walk, squirm, crawl, curl, bend, extend. And how materials can take information, have logical decisions, have programs, how we can basically embed information in materials and utilize the materials to do something.

**ST:** There's lots of other things that we're interested in like assembly, disassembly, replication, growth, metabolism, etcetera. But what's surprising about all of those things is that we believe we can do that with everyday materials, that it's not some super fancy Holy Grail material that's just emerging, we've never heard before; but it's actually all of the materials around us. We can look at them in a new light.

**LT:** Can you give examples for all of these different possibilities? What the materials will be able to actually do?

**ST:** Look at wood, for example. Wood, everyone knows about wood. Wood is a natural material. We've used wood forever. But wood is a beautiful example of how information can be embedded in the material, and how we can tap into the behavior of wood to create new agency, to create new capability. So wood grain, in my mind, is very much like zeros and ones, or like ACTG of DNA. The wood grain is actually a sequence or a pattern of information that we can tap into. That's how the wood is going to behave. The grain of the wood dictates how it's going to behave if there's a moisture change because the cellulose in the wood is going to swell when there's a change in moisture. And so therefore, we can utilize that, we can read it, and we can potentially create different grain; therefore, creating different programs within the wood. And you can look at historic examples of how we utilized wood, from Japanese joinery, to ship-building, to alcohol barrels. Master craftspeople, historically, would tap into the natural property of wood to make stronger, more precise, water-tight structures using this swelling behavior of wood and moisture.

**ST:** Then in Industrial Revolution, we sort of lost that knowledge because we went to mass standardization and mass production. So now, instead of looking at wood with this beautiful, anisotropic, heterogeneous properties of wood grain, we try to make 2x4s and lumber and say, "Oh, there's a knot, throw it out. The wood does this, throw it out." We want the wood to be metal or plastic. We want it to be some homogenous material, which it isn't. And so we've lost that ability. What's interesting now is that we have these new forms of fabrication, let's say printing, let's say industrial knitting, laser cutting, routing, etcetera. We can use these new forms of digital fabrication to tap into the beautiful properties of the wood and create behaviors, augment those behaviors, amplify those behaviors within that material property of wood. And so I think you'll see that across all different materials and all different manufacturing properties, but it's like bringing the craft and the intelligence of the materials back to industrial production through new opportunities and customization.

**LT:** Can you give some more specific examples for wood and for other materials? What they can do and how they can be used?

**ST:** With wood, for example, we've done a number of projects around that where we were printing wood grain and therefore, creating custom patterns. One of the examples, we made these bowls and baskets where we would print it flat with intricate 2D patterns. We would put it in, essentially, a Ziploc bag with moisture, ship it somewhere in the world. While it's being shipped, the moisture is being absorbed into the wood, so when you open the package, the basket then grows and molds itself. So it turns itself from a flat sheet into a bowl or a basket simply by absorbing that moisture and having the right pattern. So there's all sorts of interesting applications on flat pack shipping and transformation or assembly on the other side.

**ST:** But the same thing holds true for composites, for example. We've done a bunch of work around carbon fiber, fiberglass, Kevlar. We can make active composites that sense and transform based on temperature or moisture. We did a project with Airbus for an aviation component that can do that. Done a lot of work on textiles and fibers and yarns that can morph based on temperature, moisture, pressure, pH, clothing that adapts for breathability, comfort, custom-fit, you name it. Any of these materials, we can create and amplify these active behaviors. And then they can be embedded in our physical world, the products around us, from clothing to shoes, planes, buildings, cars. And essentially, it's looking at developing smarter products. As we've all heard, any industry is interested in smart products, but without the reliance on motors and batteries and electronics, and the traditional notion of smart. The smartness is embedded in the material property.

**LT:** Can you elaborate? You just said smart materials can be used in planes, buildings, clothing and cars. Can you give examples for each one of those?

**ST:** Yeah, but each one of those is a long list, but it's almost anything you can think of. So smart clothing. A lot of the apparel industry folks are trying to make smart clothing. And what do they do? They put battery packs in your pockets, and they put electronics and sensors in your clothes. Or Nike did self-lacing shoes. So now, you need to plug in your shoes. This is where a lot of the industry is going. Most of them will say, "We have smart X, Y, Z, smart product," which essentially means more batteries, more motors, more components, more failure, more energy consumption, etcetera. And so in the smart clothing example, we're showing, "Yes, we can have smarter clothing that adapts so that it makes us comfortable no matter the temperature change or no matter the body temperature or the humidity outside, whatever." But we can do that within the fiber itself, without adding batteries and electronics and motors. We can make clothing that adapts to temperature or custom-fit or moisture regulation.

**ST:** And so the same thing goes with every one of those industries. Cars, you can look at smart interiors like: How does a car seat have custom shapes that mold to your body so you get the perfect fit when you sit on it? And then when you get up and I sit on it, it gets the perfect fit for my body? You can tune the stiffness and tune the massage features and lumbar support and all these kinds of things. And so in any of those industries, it's the same: How do we make higher-performing systems? How do we make systems that can adapt? But can we do it through materials, not through traditional forms of electromechanical actuation.

**LT:** So can you give examples for buildings and for planes? How that would work?

**ST:** The planes example, you could do the interior or you can look at the exterior. The component I was talking about is in the top of the engine, it's a carbon fiber component that we've developed with Airbus. This component typically brings in cool air to cool the engine, but it causes drag. So the traditional solution to that would be: add an electromechanical flap or add a hydraulic or a pneumatic flap, but now, you've added weight because you've added a bunch of components, you've added cost, you've added potential failure. So by solving an efficiency problem, you've created an efficiency problem. What we did was develop a single layer of carbon fiber that can morph based on pressure differential. So as the plane is flying faster or slower, this component can open and close to regulate the airflow in the engine without adding any electromechanical, hydraulic, or pneumatic systems. It's just a single piece of carbon fiber, single super light strong composite that can morph.

**ST:** In the building industry, it's the same. Shading systems, is one that we've worked on, for example. Oftentimes, if you look at what's a smart building, people will say, "Nest thermostats are smart," and we're often questioning that. If the Nest thermostat is smart, it shouldn't cost any more money. It shouldn't fail more often than the traditional one. It shouldn't take more power. It shouldn't have more components because none of those things are actually smart. You might as well go with a dumb thing because it's going to last longer, it's going to use less energy, it's going to be just as efficient or more efficient.

**ST:** So a shading system is an interesting one. There's all sorts of automated blinds, and then there's manual blinds like the ones that are behind me. But we can create films, and we've done a number of these demonstrations where these films can open and close based on sunlight. And so then, you can get a self-regulating building skin that can then optimize the amount of solar heat gain or solar exposure at any moment, that's autonomously morphing simply by the material film embedded in the facade panel, for example. So you don't need extra control and power and electronics and devices that are going to fail. It's autonomously, opening and closing.

**LT:** Can you talk a little more about your criteria for success? Clearly, complication and electrical motors are not success. But what does success mean to you?

**ST:** I'm often thinking that if there's some problem, whatever it is, if you throw enough money and motors at it, you'll solve it. But if you look at the solutions to that major problem over the long haul, it usually gets more and more simple because you realize a more elegant way to do it. And so the real challenge is: How do you find the elegant solution as fast as possible or as direct as possible? Instead of climbing this mountain of complexity, and then finding ways to weed it out and make it more simple, can we go directly to an elegant solution where there's actually less, but it does more? That's the Holy Grail. If you have the least amount possible, but it does the most amount possible, to me, that's elegance, that's success in any "smart system". The more we can do it less, the better. So we're always trying to challenge ourselves with that: Critique our previous work, critique other things in the world and say, "There's got to be a more simple way to do this. How can we amplify what's possible with less and less and less?"

**ST:** There's another road, too, which is: Any sufficiently hard problem needs sufficiently difficult solutions, potentially. That's how people typically think about it. And then sometimes, you create one solution and it gets more and more and more complex over time. And we also want to fight that, that there's a natural tendency of making more and more complexity just for the sake of it. And a lot of our work also shows us that very simple inputs, very simple systems can lead to very sophisticated, complex outputs. You don't need complex components and devices to make sophisticated behaviors and smart systems. It can be quite simple, and there's a lot of interesting examples in the natural world where that emerges, so we're trying to simplify in order to do more.

**LT:** Can you give some examples of that?

**ST:** Our project in the Maldives, I think, is maybe one good example. The project is trying to address the issues that the Maldives and any island nation or coastal region is facing, which is sea level rise and coastal erosion. This is a huge problem, and there's not really any great solution. Think anywhere in the world, what is that city, coastal town, island doing about erosion and sea level rise? They're either trying to build walls and jetties and fixed, man-made infrastructure, or they're using dredging. There's not really many other scenarios. The problem with walls and dredging is that you're basically taking a static, fixed, man-made thing and you're trying to fight nature. You're saying, "I'm stronger than you. I'm going to resist you. I will fight you," and nature almost always wins. We know that it doesn't work.

**ST:** Those barriers and walls are going to break down. The ocean is going to win. It's not going to fight nature. And oftentimes, it amplifies the effect. There's a number of interesting examples where the Army Corp of Engineers would build a structure to try to resist erosion, and then the erosion got 10 times worse. And so we know that static, man-made things do not work well with complex dynamic systems in the environment. So that's likely not the solution.

**ST:** And the other one is dredging, suck up sand from the deep ocean, pump it back onto the island. And this is a Band-Aid, at best. This is like an addiction. Basically, it's millions and millions of dollars, it's super harmful for the environment, and it doesn't solve the problem. Next year, you need to dredge again. Next year, you need to dredge again. So you know, this is a huge global problem that there aren't great solutions for it.

**ST:** So what we're trying to do is use the force of nature to build, rather than destroy. Essentially, collaborate with the natural system. Try to understand why does sand accumulate, why do islands form themselves in the first place, why do sandbars self-organize. And can we tap into that natural system to then promote the accumulation in strategic areas? And the way that we think we can do that is changing the underwater bathymetry because basically, we understand that it's the force of the ocean with the geometry underwater, the bathymetry. So if we place a different geometry with an inflatable, basically, then the ocean can interact with that geometry, and sand will be guided and accumulate in different patterns. That's our hunch at the moment, and we've done two field experiments, and we have two more coming, and we've done hundreds of lab experiments, but super, super early days. But to me, that is an example of where we are trying to collaborate with this dynamic, complex system. And we're not trying to fight it, we're not trying to make a super complicated, crazy technological solution. It's as simple as possible, but tap into those natural systems in order to promote very sophisticated, complex patterns emerging.

**LT:** It sounds like you're doing an extraordinary range of work that affects our environment, from buildings to the ocean. Are you also doing work on materials that impact our health?

**ST:** We've done some work in the medical space, from orthodontics to prosthetics, to various other devices and systems. And I think the medical space is really interesting because everyone's body is different. It's a very complicated environment inside the human body. Surgery is very dangerous, it's invasive. And because everyone's body is different, it's a really ripe space for customization. And your prosthetic needs to be different than my prosthetic, even if we have the same issue. In surgery, even if we have generally the same problem, how they solve it for you is going to be different from how they solve it for me, and it's up to the artistry of the surgeon to go in there, understand what's wrong, be able to adapt on the fly, and fix it in a really dangerous situation. So this is a really ripe space for where materials could have more intelligence of agency. The dream would be you have some material like a stent, for example, but it's not an off-the-shelf stent. It's a stent that will customize itself to you and a stent that will customize itself to me.

**ST:** And all you have to do is place it in the body, and then it'll sense the local problem, adapt, and find a customized solution for your issue, and a customized solution for my issue, with the exact same material component. And that would be embedding intelligence in the material. It could provide amazing benefits for us. It would be safer, easier to use, hopefully, more effective. And I think it really demonstrates why there's an important problem here, and how materials could address it in a new way. But every single aspect in the health space, from the exterior of the body to the interior of the body is ripe with examples like that.

**ST:** There's many other industries like sportswear and cars and planes that we've talked about, and often, the things that we're solving there are higher-performing systems: Dry faster, be lighter, be more fuel-efficient. But safety on the health side and safety in any of these is a really important one, obviously, and a really ripe one because that's where it matters the most, and that's where these tunable customizable solutions are really important.

**LT:** What are living materials?

**ST:** I think you could take it in two ways. So one way is living in the true sense of the word, "living". There's lots of research and biological materials in synthetic biology, or biology meets chemistry meets material science like: How do we promote truly living materials? Oftentimes, so wood, going back to that, it was a living material, and then we chop it down to make wooden products. It's no longer a "living material", but it could also have life-like behaviors. I'm very much interested in that side of it, too, that we could have materials that have very life-like behaviors. Transformation, metabolism, replication, self-organization, growth, evolution; these are all phenomenon and behaviors that happen in biological systems.

**ST:** More recently, we've shown all of those behaviors in computational systems, algorithms that grow and self-replicate and evolve. There has been a lot of development in robotics where robots can self-replicate, like one robot builds another robot, or robots can morph or self-organize, etcetera. And what we're doing and others are showing, that simple materials, previously inanimate materials can have a lot of these life-like properties as well, can self-organize, transform, self-replicate, etcetera. So I'm interested in that life-like qualities in materials, but there is also lots of research on truly living materials that live and evolve and transform the same way that many other living species do.

**ST:** Yeah, so in the fashion space, there's a good amount of work. Like Suzanne Lee had previously done a lot of work on growing clothing through cellulose. And there's work on mushroom growth, mycelium to grow bricks to build architecture or grow products for packaging. And so these are truly biologically living materials that then go in to make products of all sorts.

**ST:** On the other side of it, we've done a lot of work on simple materials that can have these life-like properties. So we've talked a little bit about self-assembly, self-organization. We do a lot of research on that at the smallest of scales, all the way up to sandbars, showing self-organization, which is a fundamental property of many systems in the natural world. We also showed self-replication in these little plastic spheres that are on a shaking table, and they connect together to make these circle patterns. The circles then grow to make larger ones that have instabilities. And then eventually, they divide off and grow, and divide and grow, and divide and grow, and divide like cellular mitosis or cellular growth and division. And these are just plastic spheres on a shaking table.

**ST:** The reason we did that project is because there's this legacy of showing self-replication in biology, self-replication in computer science, self-replication in robotics. But before a lot of that work, Lionel Penrose, in the 50s, showed self-replication with wooden blocks. He made these little wooden blocks, almost like toys ,and showed that you could demonstrate self-replication with wooden blocks. That was almost forgotten, in many ways, and you then saw it only happening with sophisticated computational tools and robotic tools, or synthetic biology or natural biology. And so we went back to that and said, "We can do this with simple things. It doesn't have to be complex, computational, robotic biological systems. We can do this with simple plastic spheres." And so we're interested in that like: How do we take everyday materials and simple products that have these life-like qualities?

**LT:** Can these materials replicate infinitely?

**ST:** No. In our case, you need to add food, which is essentially more of the same material. So they can't continue to grow and divide, unless you continue to add more of these components. They will continually move around until they all find stability points. So five or six spheres would make these circles that were very, very stable. Once you have all stable spheres, then it's an equilibrium point. If we kept adding them, then they would continue to grow and divide, and grow and divide, grow and divide. But it's not like they're mutating, it's not like they're evolving. They're not passing information from one generation to another. It's just pattern formation in chaotic systems that then lead to stable systems, in this case, the growth and division. In the biological sense, there's replication and growth and division, but the same thing holds true, that there needs to be some energy input, there needs to be some type of food, and there needs to be enough materials. And then often, you will get some pass of genetic information from one generation to another generation, and that's where you could get evolution or mutation, and fitness criteria, and eventually, higher-functioning systems, etcetera.

**LT:** And what could those higher-functioning systems look like? What could they do?

**ST:** I'm not an expert in the biological space, and there's probably a lot of other people working on that. I'm interested on the physical material space like macro-scale material world, and how we can build more functionality in our system. So I'll give you one example. We built this air chamber. It was basically a fan, a big fan with a vertical tank, like a lottery tumbler. And there was a bunch of these spheres inside of there, and they would assemble and then disassemble. It would fall to the ground and break and assemble, and very much like a lottery tank. But over time, a few of them connected and they started to fly. And that became a fitness criteria of flying because the other ones, when they couldn't fly, they would hit the ground and break, and then fly individually, connect, hit the ground and break. And they kept doing that. When they would fly, they didn't hit the ground and break, so they survived, it kept going. If parts started attaching again and it created an instability, it would fall and break, start again. But eventually, you found configurations that were very good at flying, and they would survive.

**ST:** And so to me, that's really interesting because that's where flight "evolved" in this system, without me teaching. I didn't tell it how to fly. I actually didn't even know that's what would happen. It wasn't like we started with that. And the things that were flying, I don't think I would have predicted would fly. It wasn't, "Oh, oh, it's a wing. Yeah, that's going to fly." It's a structure that just evolved the capability to fly. So it's a really simple kind of dumb example, but to me, it shows that humans are not the only ones that can design. The human was designed not by someone designing us, but by the interaction of materials, design functionality and the assembly emerges. The same thing with planets. No one's out there 3D-printing planets and designing planets. Planets emerge on their own. Same thing with weather, the same thing with geology, the same thing with biology and chemistry. Lots of things are designed and built from the bottom up.

**ST:** And so I'm excited about that, that you could design structures where the performance and functionality could evolve, could work with you as a collaboration. So whether it's the surgery example or the medical example, whether it's flight, whether it's structural optimization. You could imagine building a structure that as you load it, the structure is able to adapt and change so that it creates a stronger thing or a more flexible thing. I'm interested in where design can adapt and evolve with the materials itself, not saying, "I am the smartest designer, I know how it should be, and I'll tell either a human or robot to fabricate it. Can you collaborate with the materials where design and functionality evolves?"

**LT:** It sounds like you're working on two different paths. One is to create specific properties, maybe the property for materials to repair something; and the second is to allow the materials to evolve and see what they develop into.

**ST:** Yeah, and those two paths are very interesting to us, very important, and hopefully, they come together. Sometimes, you want to have control over what's going to happen, and I think about the automotive or aviation space. You don't want to be in a plane and the wing is trying to figure out how to fly. There's a lot of concerns about that in terms of safety factors and...

**LT:** Of course.

**ST:** You want it to be here or you want it to be here. We want to know it's going to do what we said it was going to do. There's no room for just making it up on the fly. Even if there is a potential that a better version of the plane wing could evolve, that's not the time and the place to do that, right? So there's so many examples where you need to understand exactly what's going to happen, and that is when, often, top-down design holds true or is the dominant mode. And then we're trying to design materials that can adapt their performance within a range. Like the Airbus example: Can it go from here to here to control the opened and closed state of the valve to control the air flow? A lot of times, working on the material properties to give it some new capability, but design, in some ways, has been predetermined. We're doing top-down design with bottom-up behaviors.

**ST:** But more ambitiously, I'm probably much more interested in the other side where design also emerges. And the sand in the Maldives is that example. It's very much like gardening, for example. Like in gardening, you don't sculpt the flower. You don't have control over all the ingredients. You have control over a couple dials. You could control maybe some of the ingredients, maybe the watering. You can control the soil, or you can control maybe where it is, but you don't have control over everything. You have to collaborate with the medium. And by doing that, something emerges that neither one could have done on its own. And I think the same goes true for the Maldives project or many of these, that the design that may emerge, hopefully, could far outperform something we could have pre-determined. And in that way, it's symbiotically designing it, it's collaboratively designing it with the environment.

**LT:** Fascinating! Before I ask for the 3 Takeaways you'd like to leave the audience with today, Skylar, is there anything else you'd like to discuss that you haven't already talked about? What should I have asked you that I didn't?

**ST:** Maybe the biggest thing is it's really a shift in mindset, more than anything else. I'm at MIT, and we are all about pushing the envelope of what's possible. And one caveat is that we are a research lab, so our goal is to go from impossible to possible. That's the space that we play in. And every day, we try to push the envelope about what's possible. And if it's not possible, try to figure out: Can we do? How could that happen? Wouldn't it be amazing if X, Y and Z? Why doesn't X, Y and Z? Those are the kind of questions we play in. But a lot of times, myself and colleagues at MIT, and lots of other people and companies around the world, we get caught up in the technological approach or the newest, latest X, Y, Z technology. And I think, instead, it's actually about opening our eyes and shifting our mindset. It's really more about a collaboration and about the symbiotic relationship with the materials and with the environment that we've been talking about. I think that is actually going to lead to much more novel and innovative solutions than the next new, brightest, shiniest gadget. It's about collaboration, at the end of the day, and that's less sexy than a big, shiny, new toy, but I think that'll lead to bigger outcomes.

**LT:** Skylar, what are the 3 takeaways you'd like to leave the audience with today?

**ST:** One of them is that computing and intelligence are physical. We often get caught up that computing is in a computer, and computing, it is in robots, and it's about silicon, and it's about zeros and ones, or intelligence now is artificial intelligence. But all of these things are material. Silicon is a material, and intelligence in humans evolved from materials; soft, squishy, gooey things, biological materials. I feel like we've lost sight of the fact that we can communicate, we can compute, we can build complex intelligence systems out of simple materials. And I think we've lost sight of that over the past decades.

**ST:** The second one is that no matter what industry or discipline you come from, we're all interested in smarter things: Smarter products, smarter manufacturing systems, smarter cars, smarter buildings, smarter environments. And I think the future of all of those things is materials, not motors, not mechanisms. I think materials is really how we will make smarter systems that are more sustainable, more elegant, more adaptive, lower energy, lower cost, lower components, etcetera. So materials are the future of smarter, not robots and computers.

**ST:** And the third one is about the environment. We have massive challenges facing us, whether that's climate change or sea level rise, emissions, etcetera. And I'm quite optimistic that we will understand the challenges ahead, but I'm slightly less optimistic, yet hopeful that we will see it's not about the technology that we'll solve these problems. We need to get out of our own head and get out of our own ego that we'll solve these problems through crazier and crazier, shinier and shinier technology. But I think it's about the collaboration with the environment. We need to stop and listen. What does the environment want? Why is it doing what it's doing? You can't force it, you can't fight it; we need to collaborate with it. And I think that the biggest challenges we face in the environment need to be through collaborations through materials in the environment, not fighting it.

**LT:** Thank you, Skylar. This has been fascinating. I also really enjoyed your book, Things Fall Together, on the New Materials Revolution.

**ST:** Thanks so much. It was a pleasure to talk to you.

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