# Skylar Tibbits on THINGS FALL TOGETHER: A Guide to the New Materials Revolution for Princeton University Press Ideas Podcast

**Marshall Poe**
Welcome to the New Books Network.

Hello everybody. This is Marshall Poe and I'm the editor of the New Books Network. And this is an episode in the Princeton University Press Ideas Podcast. Today, I'm very happy to say that we have Skylar Tibbits on the show. And we'll be talking about his terrific book, THINGS FALL TOGETHER: A Guide to the New Materials Revolution. It's out from Princeton University Press in just a couple days, June 15th, I think. Skylar, welcome to the show.

**Skylar Tibbits**
Yeah, thanks so much. Pleasure to talk.

**Marshall Poe**
Could you begin by telling us a little bit about yourself?

**Skylar Tibbits**
Yeah, sure. I'm faculty at MIT Department of Architecture and co-direct the Self-Assembly Lab. I have a background in architecture and then went to MIT and did degrees in computer science and design computation.

So, I sort of got into this world coming from an art and architecture space and then got into computing, robotics and fabrication which then led to materials.

**Marshall Poe**
That's cool. That's really cool. Can you talk a little bit about the Self-Assembly Lab?

**Skylar Tibbits**
Yeah, sure. It’s a research lab and we're, you know, mostly focused on inventing new material properties, new fabrication systems, trying to rethink the way that we design, fabricate, and interact with products or with our built environment.

We do a lot of different research in different areas; mostly the length scale that we work on is from millimeter/centimeter up to many meters—pretty macro-scale stuff. And, you know, we work with different industry partners and a lot of different projects, everything from like footwear to clothing to cars, planes, and buildings all the way up to now like islands and landscapes. So, there's a lot of different research but it is all about how simple materials can be activated with forces from their environment and have new behaviors, new capabilities.

**Marshall Poe**
That sounds very cool. I'd like to watch you work.

So, let me ask you this question. Why did you write this book? And what did you hope to accomplish with it?

**Skylar Tibbits**
Yeah, I probably have two reasons I was interested in writing this book. The first being that, you know, over the past decade or so there's been an inundation of like "smart things," like a "smart" house or a smart car or a smart shoe, or a smart whatever.

And we increasingly see that as meaning robots. So like a smart house means buy more Nest thermostats, or Nike did the self-lacing shoes, and now you've got to plug in your shoes at night. Or there will be like smart jackets or smart cars or whatever. And they're always linked to robotics and that was just a really strange relationship that "smart" now means robot. I was interested in challenging that notion and trying to set a different vision for the future of what "smart things" are. Before we had robots, everything that was smart was material; everything that was smart was living or biological or chemical and these were, you know, simple materials that had agency and could respond to their environment, could make decisions, could sense and react.

Through our work and many of our colleagues in this space, I've grown to realize that there's a completely different perspective on what it means to be smart. And that's through the lens of materials, not through the lens of electromechanical devices. And if we can get there, that means we can eliminate or reduce our reliance on heavy fossil fuels and batteries, motors and parts and complexity which increases cost and often increases failure. So, it's this realization of where a lot of these industries were going and I wanted to show a different perspective of what smart products and smart environments can be in the future and really, it's just bringing them back to being simple. Being really fundamental simple materials.

That was one of the reasons and then the second was just that, you know, over the years at the at the Self-Assembly Lab, we've done lots of different projects and have fallen into these really fascinating and strange principles that we use all the time that are not obvious to most people. If you just think about the process of self-assembly or self-organization, that's not really an intuitive thing. Unless you're a biologist, you know. If you're a kid or you're at home and you want to build something, you don't just like take a bunch of Legos and throw them in a washing machine. You build them like piece by piece, you have an idea, a top-down vision of what's possible and then you build them, and you force things together. But in much of the biological and chemical world or even like, think of planetary scales, that doesn't happen. Things come together on their own.

And so, there's a bunch of these really surprising principles that we've come to learn and love and work with every day that most people don't think about. So, I wanted to be able to articulate those fundamental principles for how this stuff works.

**Marshall Poe**
With regards to your first point about smart devices, when I was reading the book, I was reminded of the most hated smart device in the world, and that is the smoke detector. Because, from my opinion, from a design standpoint, these things are very badly designed because

people disable them. I don't know why you would build a so-called “smart” device that requires or moves people to disable it. So can you work on that at the Self-Assembly Lab?

**Skylar Tibbits**
Yeah, we’ll get right on that. But yeah, like in all honestly, I think that's what happens to a lot of our smart devices is that they are not really smart. We're always thinking about if the smart thing costs more or the smart thing fails more often, or the smart thing is way more annoying and forces me to turn it off, actually, I might as well go with the dumb thing and be safer, better, cheaper or whatever.

**Marshall Poe**
No, that's right. But I was thinking actually, I mean, the smoke alarm has an aural aspect to it. It wakes you up in your sleep, but if you could design a kind of paint, a ceiling paint, that turned a color when it detected radon or something in the room then, well, that would do it; it would be a material that solved the problem.

**Skylar Tibbits**
Yeah and you know under the hood like the thermostat, for example, is a classic one and the old-school thermostat is brilliant in the sense that it's a simple bi-metal strip and inside that is a coil and it expands or contracts with very subtle temperature changes. That’s what basically tells you what temperature you're at and you can adjust the dial. This coil is, you know, going to outlive all of us. It doesn’t take any electricity to run this simple bi-metal strip, it’s just morphing based on the material properties and you'll see that all over the place. That's in braces, that's in stents and medical devices. It's in car engines and in your home. There's lots of these examples that are just brilliantly designed around material properties. But we sort of ignore all of those and go to spend lots of money on motors and make it smart with a bunch of robots.

**Marshall Poe**
So could you tell us what the phrase “programming materials” means?

**Skylar Tibbits**
Yeah, so that emerged as I was saying before where my background from computer science meets architecture in a way. It's like, what do we mean by embedding information into something? And how do you program something? How do you embed a program into it? And that could be as fundamental as like DNA. DNA has a sequence of ACTG and those are essentially the code, and that encodes everything about construction and behavior, all of the fundamentals of biology, and the same thing goes for a computer program. We are essentially embedding information into this system that then has logic and can have instructions and conditional statements, loops, objects and classes and all these different things. And so the question was, how do you embed information into materials? And even more than that, how do you embed more sophisticated programs into materials, that then give those materials agency? And those materials could just be a simple sensor and actuator so, “if *this* happens, do *that*.” Or it could be more sophisticated programs where it has multiple inputs and multiple outputs and could make more sophisticated decisions.

It’s essentially trying to design and fabricate and work with those materials in order to create more agency in them. So it's, it's a little bit misleading in the sense that we don't mean “program” in the more contemporary notion of program, like, program with electronics and program with a computer; we mean it more in the fundamental way. That if you went far before that, you would get to mechanical computers or you would get to, things like an abacus, or you would get to like really fundamental things like smoke signals. That's a really interesting way to transfer information and communicate between two points that isn't about, you know, electrons and zeros and ones.

And so we're trying to figure out the same way and you know, your example of the wood earlier is a beautiful example of that wood grain encodes the ability to sense and react so that the pattern of that grain is essentially like, you know, zeros and ones or dashes and dots or ACGT's, a pattern that when moisture is around is going to dictate how that wood behaves, how it senses and reacts. If you change that pattern of the grain, you get a completely different behavior. It's literally the same as a computer program and it's embedded directly in the piece of wood.

**Marshall Poe**
I'm sure my contractor, Gary, knows that. He just doesn't know he knows it. Yeah, and this is what you call "active matter," right, in the book?

**Skylar Tibbits**
Yeah. And the fundamental question is, how do you create that pattern? You know, wood naturally that that emerges and it's the same in the case of DNA. Although now there's more contemporary examples of creating custom sequences of DNA, and some of our research, we've created custom wood patterns, etc. But that's the question is, how do we create unique, arbitrary patterns that mean something, you know, that the wood can transform into a precise shape that it never would have done before?

We tap into the properties of the wood in order to make it literally active. And so, when we say "program," we literally mean designing some patterns, some sequence and behavior that we can embed in these materials, and then we want them to become active. So, we're trying to make materials active. And that's why we talk about it as "active matter."

And I think about that as a much broader category of literally any material system that's active, that could be sensing and transforming: changing shape, changing property assembling itself. We want these systems to become active and "life-like" in a way. Most of our human-built world tends to be quite static and kind of cold and dumb and just sits there. The rest of the human and biological and chemical world tends to be really, really, active. You know, think about humans, growing and morphing and moving and dancing; think about plants and animals and even think about weather and, non-human things [they are] dynamic.

And so it's interesting that most of our human things tend to be quite static.

**Marshall Poe**
This is a bit of an aside, but I think it's important because it's important to everything you say in the book. And what I mean is the idea or the fact of entropy--you talk a little bit about entropy and explain what negative entropy is.
**Skylar Tibbits**
Yeah, I mean, the, the average perspective on entropy that most people will hear about is you know, "things fall apart," that everything good in life comes to an end and most things go from order to disorder. That's the kind of like average person's understanding, which is not totally

true and not scientifically what we would describe as entropy, but we often see that happening. And so some people will say life is essentially reverse entropy, that all of life is going against that; it's building order from disorder.

And as we live and grow, we are essentially fighting that and building more and more order. And often the things that we make we, you know, add energy and we then put things together and build structures. But the way that I kind of shift the definition away, in a way, is to say; "Maybe it's more about moving towards a more comfortable state."

Often the most comfortable state or the easiest thing to do is for things to go towards *dis*order, or for things to fall apart. It is pretty easy for things to fall apart, but if you can create the right conditions, things could potentially just as easily come together as fall apart. It's less common but it is possible that things can create order, and so really the goal was that we're designing these systems that have *just* the right environment, *just* the right ingredients in order to build order from disorder.

**Marshall Poe**
That's very well stated I get it now, completely. Could you tell us what self-assembly is?

**Skylar Tibbits**
Yeah. So self-assembly is the process where disordered parts build ordered structures without humans or machines. So the principles of self-assembly are how humans are built, from disordered biological material that then comes together to build all of the functionality and design and intelligence that we have as humans.

But the same goes for almost everything that's not man-made. So you can look at cooking, baking, and brewing beer and all sorts of interesting things; you could look at gardening, you can look at planets, you know, there's no like big 3D printers printing out planets. There's no one saying like, "I want design a planet like this and I'm going to build a machine to make this planet." And the same thing for DNA, there's no like little sledgehammers and screwdrivers, you know, assembling this precise DNA thing to make a human. All of these things are designed and built from the bottom up, that they self-organize and self-assemble into this final structure that has functionality. It has hierarchies and complexity and behaviors and intelligence.

And so the question is, why don't we use that in our human-built world? Almost everything that we build as humans, with with a few exceptions, are designed by some genius designers, architects, engineers, and then instructions are sent to humans or robots to build it part by part. So, everything in that process is top down, whereas almost everything in the natural world is built and designed from the bottom up. And so that's the question we're really interested in this: Can we tap into this phenomenon and and use it for human design, construction, fabrication, etc.?

**Marshall Poe**
You give a great example of this in the book and that is the self-assembling table. Can you tell us about that?

**Skylar Tibbits**
Yeah, we've done a couple of furniture pieces. We did a table and we've done a chair, you know, the simple example that almost everyone asks me is, "Like, oh, do you mean IKEA? Is that what

you do?" And we really don't mean that. It's funny because that's also like, literally like you're the self and you're assembling, but that's not what we mean by self-assembly. You could say like the future of Ikea would be that the furniture self-assembles.

**Marshall Poe**
That's what I was going to say. If you perfect that the people at IKEA are going to be on the phone in about three seconds!

**Skylar Tibbits**
Exactly. If you think about it from the future perspective, yes, that is what we are talking about: that the product, whether that's furniture or something else, should be able to self-assemble, to build itself. And that seems crazy. But there's lots of examples demonstrating that's possible. And then in our lab--and there's various other researchers out there that have demonstrated this kind of process all the way from the smallest of scales to the largest of scales---we've done it with meter diameter, weather balloons, building meter scale structures. We're now studying wave and sediment transport to self-organize islands. Then in the one you talked about, we did a chair where all the components of the chair are unique, so they're not self-similar parts, and they tumble under water and then come together to build this arbitrarily designed chair. And it's not like this chair is found in nature and this is like a fundamental shape that can only self-assemble; we can do arbitrary designs and they come together.

The table is a different version of that, which is that it should go from flat to 3D. Often with products one of the challenges is how do you ship it around the world? And you want to minimize the volume, the air that you're shipping in the package. So IKEA has perfected the flat-pack, but it then takes a lot of assembly. So, a bunch of our work has looked at how do you ship things flat, and then with some minimal input get it to transform into 3D? And so, the table was that, "can it be shipped flat and then jump into a three-dimensional table?", and the chair was separate parts that come together under water in order to assemble this precise chair.

**Marshall Poe**
That's very cool. It's just very cool and I hope you perfect it because I imagine the people at IKEA would want to do business with you.

**Skylar Tibbits**
There's a lot of frustration in building your own furniture!

**Marshall Poe**
Right! There's a sentence in the book that intrigued me and I'll quote it: "Robots do not always need robotic mechanisms to function. Can you explain that?

**Skylar Tibbits**
Yeah. In the the world of robotics, you know, when I was a grad student, I was working with Neil Gershenfeld's lab at the Center for Bits and Atoms under a DARPA grant called "Programmable Matter." And at that time there's lots of researchers under that grant doing what they called "programmable matter," which meant robots.

And, we thought about it in the classic term of like programming, electronics, and motors and mechanisms to do things: to move, crawl, swim, squirm, go from one thing to another. But since that time, so about a decade later, almost all of those researchers have moved towards soft things: materials that behave like robots but aren't built with electromechanical mechanisms and clunky gears and massive parts that you would typically think of.

Most of that field has shifted towards “soft robotics.” So there's now like this booming space of soft robotics and that is often like soft, squishy, gooey, material things that can sense and react and transform and do all of the fundamental things that robots can do, but they don't have the traditional parts of robots.

So, what I'm trying to argue there is that, you know, it's a similar space that we started out with and, most of the time we want a quote unquote “robot” because we want it to have some function. We want it to have some behavior, to sense or transform or remove or walk or curl; we want to have something that's smarter and we agree with that, but the way that we achieve that doesn't need to be constrained by our conventional notion of “robotics” (with electronics and sensors and motors and electromechanical systems). So we can demonstrate all those behaviors with simple materials.

**Marshall Poe**
I'm reminded that we just bought a Venus flytrap and the purpose is to get rid of flies and it is a little robot that does this--it really does! I was amazed that it worked, but it does. It has some kind of “fly crack” that it gets the flies to go in the little jaws or the Venus flytrap and then closes much faster than you thought a plant could ever do anything. I highly recommend this to our listeners, because it is mind-boggling.

**Skylar Tibbits**
Exactly. Yeah and there’s a lot of examples where a traditional robot might make sense, but most of the ones that we come across could move towards the Venus flytrap version. The simple material version would be much better. You know, you don't really want a bunch of batteries and motors in your shirts and shoes.

**Marshall Poe**
No, you don't. You really don't. I can't tell you the number of people who have said, “my Fitbit broke. ”It's like, yeah, I totally get that. Let's move on to 4D printing. We live in three dimensions, not counting time. What is 4D printing?

**Skylar Tibbits**
Yeah, it's exactly the element of time that you mentioned. Actually this came after the robots that I was working on under that DARPA grant. You know, there was a bit of a frustration that, we're spending thousands or maybe even tens of thousands of dollars building these really complicated robots, and in my case coming from an architecture world, I was building large-scale robots. But if you think about how that scales up, you don't really want to be building architectural buildings that are robots. You know, you don't want every brick to be a robot because it's going to be too expensive, too energy-intensive, too failure-prone, too complicated to assemble, so it doesn't really scale to make buildings out of robots. But you do want all that behavior and the functionality and intelligence in it. So we were then thinking about, “Well, how do we make these ‘robots’ without the traditional robotic mechanisms?” And so that's where we landed on this idea of “there's this emergence of 3D printing, what if we could 3D print things that transform over time?” And so that's why we called it 4D because we added the

element of time that wasn't just about printing static things. It wasn't just like, "Let's print some tchotchkes or on your desk paperweights."

But we were printing essentially robots or printing active things, materials that could transform. They could morph and adapt and change over time. And so that's why we called it 4D printing. And in the beginning it was all based on multi-material printing. You have different materials, you print them out with very specific geometries in two and three-dimensions and then based on the environment and the very beginning, it was all based on moisture. If you change the moisture or you dip it underwater it morphs from one shape to another and we did all sorts of things like 1D structures that fold into 2D, or 2D things that unfold into 3D, or folding, curling shrinking, you know, all sorts of different geometries and mechanisms. We even did like protein strands, you know, macro-scale versions that could morph.

And then that led to lots of other materials and research over many years about "how do we do this outside of just printing? Can we do it with knitting and weaving and extrusion and lamination? And can we do it with wood and metal and plastic and foam and, you know, lots of different materials?" But the 4D printing work was the very beginning of it that led to this sort of "aha moment" that it's totally possible to produce these smart "robots" with just materials.

**Marshall Poe**
Thank you for that. I have a question here that's about smart wearables, but I'm not going to ask it, because I think we beat in smart wearables to death.

So how do you build "from the bottom up?"

**Skylar Tibbits**
Yeah, this is what we were talking about with our self-assembly and self-organization work: that there's a couple different ingredients. So we need to be able to design the components with specific interactions; so how does one part come together to another part? And can you encode some type of logic in that? So, you know, ACTG it has different patterns that they can connect and not connect. They're going to attract or repel one another, for example, or you can think about polarity and magnets. You could think about velcro that has sort of positive and negative or male and female connections. Surface tension has something similar, like, different ways for materials to have some patterned connection. So you design, whatever it is--the chair, the some type of mechanism or the some type of structure or product--you break it down into components. How do those components come together? How do I pattern the interaction?

So the right ones connect with the right ones and the, you know, the wrong ones, don't connect. Then you need some amount of energy. So often, you know, we're putting things underwater and adding, you know, flow and current forces or we're using wind or we're tumbling or shaking. You know, you need some type of activation energy; we're really interested in using abundant natural sources of energy like wind and waves and vibration, etc., but you can use all sorts of energy sources in order to activate these things.

And then kind of one last ingredient is that you want to build in some form of error correction. So what happens, you know, the Lego example, like throw a bunch of Legos in a washing machine---and by the way there's a really fascinating research paper where researchers literally did that and you get a whole taxonomy of like what shapes come out of that. I wouldn't recommend anyone try that; you might ruin your washing machine, but it's really interesting. So, you know, there is a pattern of how these mechanisms come together but there's really no error correction that can guide certain structures to assemble and and stop other ones.

So you need to think about ways that that can happen. And you can build that into the mechanisms or the patterns of how this comes together or the geometry. There's different principles of how you can design for error correction but, you know, it shouldn't just be that any random thing emerges; you want certain things to emerge and you want other things not to emerge. And so, we design around all of those principles trying to guide certain structures to emerge with the right environment.

But we're also interested in the potential for that process to show us things that we couldn't have predicted. So there's one example where we we had this really big fan, I think it was like a meter diameter fan, and we had a chamber above it, almost like a lottery tumbling machine, and we had these particles flying around in this chamber and they would connect and then they would fly down or they would kind of land to the ground and break and then they would connect and break again very much like a lottery tumbler machine, but then eventually different structures started to connect that were really good at flying. They would just hover. And so this fitness criteria evolved to show that they could fly. We didn't design them to try to make them fly; we didn't tell them how to fly, but they started to connect and because they were able to hover, then they "succeeded," and they were able to then continue to fly and they didn't break; all the rest of them kept falling, breaking, connecting, breaking, connecting, breaking until one started to hover. So to me that's really interesting because not only did it self-assemble and build from the bottom up but it also was able to point towards like design emerging, functionality emerging, in the system that we didn't predetermine. So, it could tell us what might be, you know, an optimal flying structure without us having to design that in the beginning.

**Marshall Poe**
Yeah. We see this kind of "design from the bottom up" in spades in nature. Evolution figured out a long time ago and you've reminded me of something I think I learned in college biology about cell division. Cells not only have many error-correcting mechanisms but they have several mechanisms by which if things don't go right, they kill themselves. Yeah, they just stop. And every one of your cells has those mechanisms built into it.

**Skylar Tibbits**
Yeah and I think they also--I mean I'm definitely no expert in the biology space--but you know a lot of these principles that we're talking about they transfer across many different disciplines. So you'll see self-assembly in a lot of different scales in a lot of different domains and biology is one of the main ones, but I think also cells have counters and they have so many times that they can divide and replicate and that's what leads to, you know, lifespan and why different species have different lifespans. And so, you know, it's interesting in that space and anecdotally, if you remove that, I think there were researchers that were trying to figure out how that mechanism works, but if you remove that, that ends up being cancer--that the cells can continually grow and divide grow and divide.

**Marshall Poe**
Yeah, so let's move on. I found this fascinating. What do you mean by "design as adaptation?"

**Skylar Tibbits**
So typically, you know, we think about design as "I want to make this product for this application." But in the software space you're seeing in the past decade or so, first people ship and then they'll make updates and they'll make updates as they learn and then they keep updating the software and keep revising. It's a little bit harder to do that in hardware. So you make some machine or you make some, you know, component or whatever, it's hard to update that thing over time. And it's hard to foresee all possible scenarios of where that will be used and how, you know, it may fail. So what we typically do in an engineering space…Like, let's say you're designing a bridge, is you'll over-engineer it so it's way stronger than it needs to be. And you have all these safety factors that are really important so that with bridges, [they] don't collapse and people don't get hurt. But we use lots more material and over-engineer the structure to be super, super rigid and constrained so that it doesn't fail because you can't predict all possible scenarios

And so there's an interesting space to me that is about how do we design systems, like the one I was just talking about, where that it evolved the function of flying? Or in the 4D example where you design objects that can then morph and transform? Can we have a design process where we design something that can adapt and transform over time? So that as the function changes, it also can adapt and the design functionality emerges through the relationship with the environment or through the relationship with the user?

So maybe the bridge grows stronger where it needs to be stronger or maybe more flexible where it needs to grow flexible. Or your shoes get more comfortable because they start to learn how you use them, how you walk, or how you run, where you need more cushion, where you need more support. You know, we have products that can adapt to how they're being used and be the best versions of themselves. It's not that all products are the same and it's not that they're going to be static and disregard how you use them, but they actually adapt to the situation and get better over time.

**Marshall Poe**
The chair that I am sitting in, which I have had for decades, was over-engineered and was designed not to fail, at least fail catastrophically in such a way that it'd kill me. But I can tell you, it's become really comfortable; it's like it now is my chair. It fits me really well. So that was kind of an accidental design as adaptation.

**Skylar Tibbits**
There's a bunch of examples like that, like a well-worn pair of jeans or a leather baseball glove or a hat or shoes. There are many examples where almost accidentally, these products can adapt to how they're being used. And those are fascinating examples for us. And then we want to basically amplify that, to really design-in that feature, so that our products adapt to us.

**Marshall Poe**
Yeah, this next question will also be of interest to the people at IKEA. Can you talk a little bit about self-repair?

**Skylar Tibbits**
Mhmm. There's a bunch of researchers looking at many different material systems and trying to build in the functionality of self-repair. If, if you get a cut, your skin will repair itself or there's

many species that, you know, the tail gets cut off, it'll then regrow. That self-repairing mechanism we see often in the biological living world and sometimes there's really interesting examples of how that can happen in materials, you know, non-biological materials.

There are researchers looking at self-repairing concrete, for example, or different polymers and composites like carbon fiber and Kevlar and fiberglass, and metals…many different materials that often, if they have some failure point, they just get worse and worse and worse. And sometimes it'll be a catastrophic failure, and sometimes it'll be more like ductile and it'll bend.

But now, sort of at the cutting edge of this research, people are looking at "how do we design these materials so that if there is some crack or some impact or some failure moment, it can actually repair that and potentially even get stronger than it was before?" And there's a bunch of different motifs on how that could happen. Where you crack something and then it releases something else, or oxygen hit something and catalyzes the material. Or you can do it like structurally or geometrically, where you have different geometries that when one thing opens up it then fills a void of another thing. So, there's a lot of interesting research coming out about materials that can repair themselves much like humans or many living systems repair themselves.

**Marshall Poe**
I'm kind of into airplanes and I always have been, and there's a thing: there's the technology of the self-sealing gas tank, fuel tank. I'm not going to ask you to explain it, but this idea has been around for a long time. So if a gas tank is punctured it somehow heals itself. I have no idea how that works, but it's a good example of self-repair. Near the end of the book you write this sentence, "Today we have the opportunity not only to rewrite our relationship with the physical world so that we are no longer passive observers, but active collaborators." What did you mean by that?

**Skylar Tibbits**
Yeah, I am really interested in true collaboration. So, if you and I collaborate on something, the goal is that the other person brings something to the table that you couldn't do or wouldn't have thought of, or you have complementary skills and you collectively do something better than one person could do. That's like the ideal collaboration.

And when we look at our physical environment around us, whether that's the built environment or the natural environment or the products that we design, it's very much the opposite of that. It's almost like materials are our slaves and we say, "Okay, brick, go here because…I told you to be here, you're going to be here and I'm going to rivet you together so you stay there." There is no collaboration with the material medium, it's forcing stuff into place. We're not actually listening to what those materials want to do. We're not collaboratively designing a better structure together, like I was kind of hinting at it the flying structures. And in our environment, you know, that's maybe the worst example, we're definitely not collaborating with our natural environment, we are more or less just destroying it.

So, in all of those cases, I would be much more interested in like a true collaboration where we think about, "Okay, I'm going to use an example you talked about earlier: What can this wood do? What is the wood really good at? It's good at sensing and responding to moisture, you know, it's good at carrying load in a certain orientation and really collaboratively trying to design around the material properties and then design around the environment with which it's going to be used. So, if you look at like Japanese joinery or you look at shipbuilding, or alcohol barrels… For example, historically, with master craftspeople, they would utilize the swelling nature of wood to make extremely precise, extremely strong and watertight structures by collaborating with the material properties of wood and understanding the environment with which it's going to be used. To me, that's a really awesome collaboration and we've sort of lost that and I think there's this lineage from the craft age to the Industrial Revolution when we started mass-producing, you know. You saw all the wood-workers kind of go away and we started making standard two-by-fours and we ignored the grain and the beauty and an-isotropic properties of this wood. We stopped listening to it and we said, "Wood, you're going to act like metal or plastic and if you're not, we're going to throw you out and say you're bad." We stopped collaborating and listening to the material. We don't really care what environment. We're going to use all the same two by fours and lumber in, you know, any place in the country or in the world, and so it's not really a collaborative environment. We're very much interested in trying to rebuild that collaboration, listen, and collaboratively design structures that wouldn't be possible if you weren't tuned in to those properties of the material or the environment.

**Marshall Poe**
The two by four, of course, is no longer "two by four." So not only do we not pay enough attention to it; we have it badly named. So I want to end the interview with what is kind of a philosophical question that occurred to me while I was reading your book. And as far as I know, people in the West at least have always made a very strong distinction between organic things and inorganic things. Humans are organic things and rocks are inorganic. This is like the strongest possible distinction that we have. A rock is not a human. They are entirely different but it seems to me what you're saying in this book really blurs the line between organic and inorganic. Can you talk a little bit about that?

**Skylar Tibbits**
Yep, I'm very interested in that. I actually taught a design studio a number of years ago that we called "The Origins of Life" and the premise was that if you ask anyone, "What is life?" there's all these characteristics that they'll describe like self-replication or self-assembly or metabolism, growth, evolution, intelligence, you name it. There's these characterizations that we say like, "Okay, these things make up life." And if you go into every single one of those categories, they have been demonstrated in both biological systems, as well as computational systems like algorithmic. In many cases, simple material examples that are inorganic that are, non-biological materials have that same property. And so the question is, "If you put all those together, would we call it life?" And I doubt it, you know, I think that basically it's… we just move the goalposts all the time.

And we basically, unless it looks like us or looks like something that we understand as living, we don't call it living. And so, there's really fascinating examples from biological self-replication to robotic self-replication to Lionel Penrose did this amazing example I think in the 50's with these like wooden blocks that self-replicate and it's just fascinating (like just fundamental, simple wooden blocks that can replicate).

And in every one of those categories, there's lots of examples like *that*, that I really, really love. That these behaviors are able to be demonstrated computationally, biologically, and through materials. And so that to me points to the perspective that these are not just what we call living today. These are not just in like biological organic materials. These are the fundamental principles that can be demonstrated in many different things and that could shift our notion of what we mean when say something is living or what we mean when we say something is intelligent. We can actually expand that definition and, maybe that's useful in our quest for life on other planets. For example, we might be able to broaden our definition of what we mean because it might not be this carbon-based, you know, life form that we know of and might not have a lot of the same kind of attributes.

To me, it's not really about the quest for life; it's more just like the quest to activate matter and the quest to tap into all of these capabilities. Can we make intelligent material systems? You know, all of us, our intelligence is built out of materials like soft, squishy, materials; it's not built out of electronics. It's not built out of computers or robots. We're built out of matter. And I think there's a lot of fascinating examples where that could happen in both organic and inorganic systems--kind of push the behaviors forward and lead to that collaboration that I was talking about. Lead to a smarter environment and a smarter world that's not just like, "We're smart. Everything else is dumb," you know? But that we could see the intelligence in both organic and inorganic systems.

**Marshall Poe**
Yeah, what you've just said has massive implications. That's a lot of weight to carry. Yeah, let me ask the traditional final question on the New Books Network. What are you working on now?

**Skylar Tibbits**
A bunch of different research projects at the moment, but maybe one of the biggest, both in scale and in applications, is a project in the Maldives. We have collaborators there looking at how to grow islands using wave energy. And so, you know, this gets back to your question of "organic versus inorganic" and, islands are, depending on where they're at, often made out of things like sand or rock or volcanic structures.

And these things self-organized. Islands emerge on their own; sandbars grow and evolve and shift and change. And the question is, "How does that happen? Like, how do islands emerge? How do sandbars form? Why do coastlines erode?" There's whole disciplines of people just studying this, and we became really fascinated in it because it's a very, very clear example of self-organization similar to what we've seen but at the largest of scales--like, literally making land that self-organized. No one's out there like sculpting this, although there is this whole space of dredging. Any coastal area or island nation will often use dredging where they basically suck up sand and then pump it back to the beach. And we're trying to oppose that. That becomes essentially an addiction and a band-aid that doesn't actually solve the problem and cost lots of money and it's really harmful for the environment.

So, the question was, "Could we tap into that natural ability to self-organize and try to guide and promote the accumulation of sand in useful areas? Could we rebuild beaches naturally by using wave to grow, rather than erode, or could you grow new islands doing the same thing? Could you use this as a tool to overcome sea level rise? Perhaps…" And that's a really fascinating one and widely applicable. Obviously, there's lots of coastal regions around the world and island nations, and they're all facing erosion and sea level rise challenges in the future. And coming up with some new perspective on how we could do this in collaboration with the massive forces in our environment, like with waves and tsunamis, and storms and currents, we're trying to tap into that to build rather than destroy.

**Marshall Poe**
And you probably get to go to the Maldives. Do you?

**Skylar Tibbits**
Yeah, I've been there a couple times and am hoping to go back in the Fall. We have a National Geographic grant around this to do research there. So, you know, it's not the worst place to work.

**Marshall Poe**
Alright, let me tell everybody that we've been talking to Skylar Tibbits about his terrific book, THINGS FALL TOGETHER: A Guide to the New Materials Revolution, out from Princeton University Press in 2021. Skylar, thanks so much for being on the show.

**Skylar Tibbits**
Yeah. Pleasure to talk to you. Thanks for having me.