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The Solari Report

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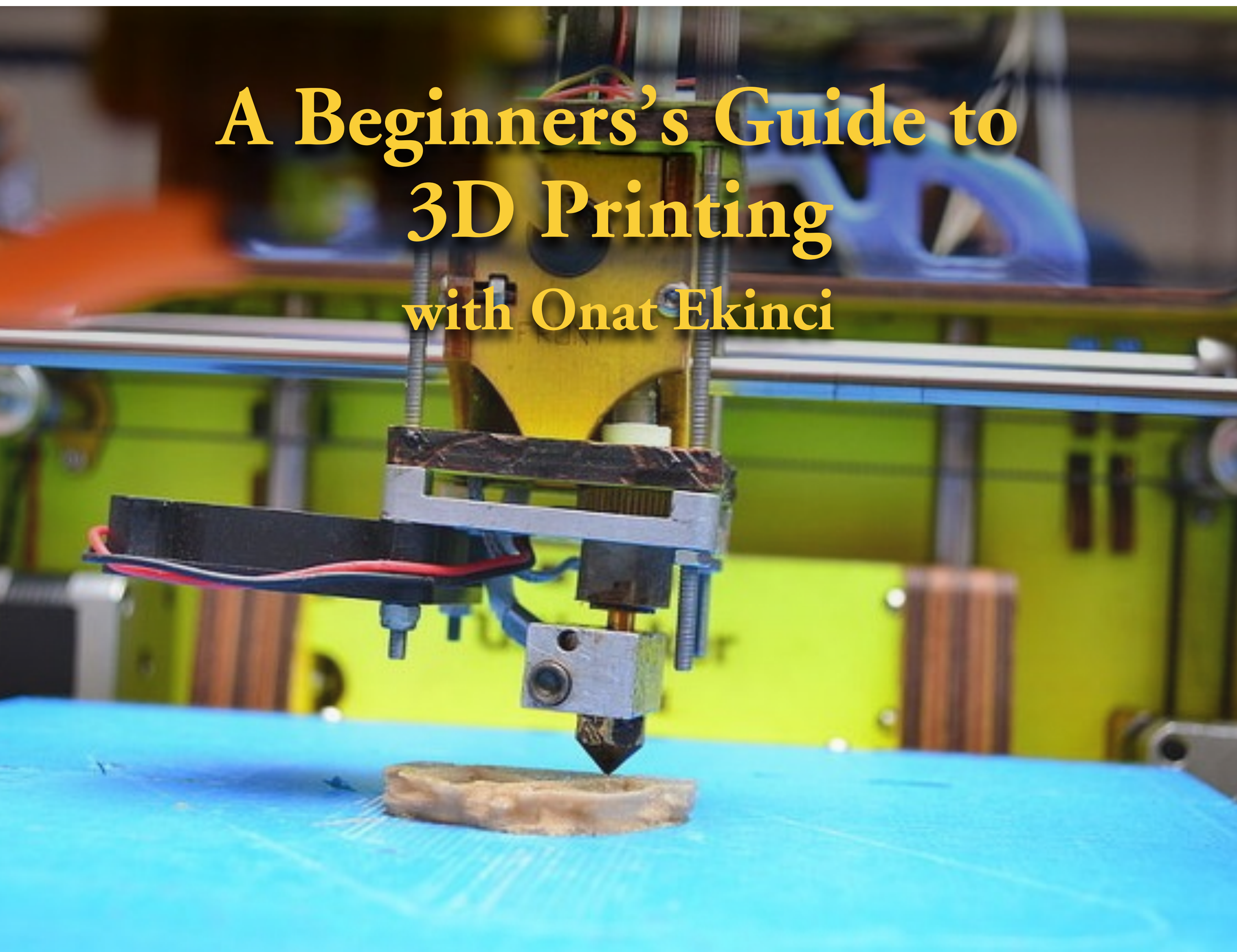
A Beginners's Guide to 3D Printing

with Onat Ekinci



A Beginner's Guide to 3D Printing

October 10, 2013

C. AUSTIN FITTS: Okay. Well it's my pleasure to welcome you to The Solari Report.

Once a week, one of the things I most look forward to is talking with Onat Ekinci. He is an engineer and a research consultant, and is the creator of Innovation Rex, which I encourage you to check out. It's linked from the blog post for this Solari Report. He advises me on all things technological. He has a wide background. He's an engineer by training, he has a PhD in Mechanical Engineering from Montreal Polytechnic, and he's published in fields related to machine design and air analysis.

He has wide experience, including with surgical robots and aerospace and power utilities and he has the integrity of a well-trained engineer, but he is remarkably creative for someone with that background. One of the reasons I find that to be so invaluable is, if you look at what's happening in a wide variety of fields within technology and science, we're talking about different specific innovations that then dovetail with others. We're getting very innovative results, not just within fields, but across sectors.

It takes a lot of creativity to look at it and think about it, which is why I'm so grateful he's in my life. So, Onat, welcome to The Solari Report.

ONAT EKINCI: Hi, Catherine. Delighted to be here with you.

C. AUSTIN FITTS: You're coming in from Montreal, correct?

ONAT EKINCI: Correct.

C. AUSTIN FITTS: Okay. Well, I hope it's a little bit cooler there than it is here in San Francisco. We're talking today about 3D printing. One of the reasons we wanted to talk about 3D printing is you can't open the papers these days without seeing articles on 3D printing. So why don't we start off by talking about 3D printing? Basically what is it and why is it something that is worth knowing about?

ONAT EKINCI: Well 3D printing is along side to manufacturing. It's a process. First you prepare your design files on software, and then you input your files into the 3D printer processor, and then depending on the 3D printer type, the print head or other source of materials, or the laser beam, or the fine layer of powered material. After that, layer by layer you put your material. After the first layer is all defined, the print head returns and forms another layer, and so on so that the layers accumulate on top of each other and a 3D object is created. So this is the future. Why is this important? The first one is the democratization of manufacturing to liberate you from the constraint of traditional manufacturing.

It gives you new meaning for entrepreneurship, and at the same time, for personal expression. This is also very closely connected to the maker movement and rising technological DIY culture. The 3D printer allows us to put our idea into reality. The way you switch from maker to entrepreneur is much, much shorter because 3D printers are getting cheaper and more accessible by the day. You have more possibilities of seeing your dream completely in front of you.

Coupled with this, there are also financial resources offered by crowdfunding and eventually can also help you put your product in the market much more efficiently. If you have your idea, you can make a prototype on a 3D printer. Based on that, you can attract investors from crowdfunding sites. So this democratization of manufacturing offers many possibilities. The first one is simply that you can print your files, your ideas, easily on your desktop at home with your 3D printer.

The second point is that you can share your file on online CAD (Computer Aided Design) model databases such as GrabCAD, or printing service databases such as Thingiverse. So you can share your ideas using just your product. The third point is that you can send your file to printing services for printing. So, you don't have to have a 3D printer for yourself at home. Printing services, like Shapeways, where you can send your files for printing. So, that's for the democratization of manufacturing aspect.

The second aspect is mass customization. The current chiller app in 3D printing is personalization. Producing products for a market of one person is really the idea of 3D printing. There are several possibilities. The first one is obviously you can easily manufacture your own personalized ideas into being through 3D desktop printers at home. Neil Gershenfeld, the father of the Fab Lab movement, and one of the pioneers in the Maker movement, talked about the new literacy: a literacy that can provide you more freedom of expression. He put this literacy as equivalent to the popularization of creating writing after the Renaissance. So, this is a huge possibility with personal fabrication at home and mass customization at home.

"The current chiller app in 3D printing is personalization. Producing products for a market of one person is really the idea of 3D printing."

The second point is that the industry can go through this mass customization way. Companies can offer personalized products to their customers at a more affordable rate. Of course this will depend on the product. Some of the more popular applications today are dental crowns or hearing aids in the medical industry; they are all done by 3D printing technology. More and more prosthetic limbs are coming, too. So customized products by industry is also a very promising avenue.

The third point that makes 3D printing important on the industrial side, not the personal fabrication point, but really the technological capability of the technology of 3D printing or just in manufacturing technology. This issue is not covered in the media. There are very distinctive advantages of 3D printing in the industrial side, too. For example, 3D printing helps in the reduction of tooling. As an example, in sand casting—

C. Austin Fitts: Wait. Just tell me what sand casting is.

Onat Ekinci: Basically, you make a sand mold, you put some patterns in your mold, which is of sand, and then you remove your pattern and the mold is solidified. Then you put molten metal in that mold. So, in this way, you obtain your product. But the problem with this is the construction of the mold. It takes a lot of time, you have to make a very intricate pattern inside the mold, and it's a huge process, especially if your product is complex and big. It's really difficult to do those molds.

So, 3D printing and manufacturing eliminates the use of these costly attachments and really eliminates the time for manufacturing this mold. You can build very complex molds with machines out of sand. Companies like ExOne or Voxeljet, offer the machines to make sand molds; sand mold production by manufacturing.

The other advantage of the 3D printing industrial side is the reduction of assembly. Like General Electric aviation, they started to produce fuel injectors and fan blades using manufacturing technology. The advantage of this is that in the traditional process they have to weld their own metal parts together, which is constant work. With 3D printing you have in one setting the whole piece at the same time. So, it offers many advantages on the labor side or the tool side. Also, Boeing and Northrop Grumman, they started producing air ducts for the aircraft through identical manufacturing.

So, it has a lot of advantages, but after this glowing introduction, I would also like to give some warnings that you don't hear that much in the media. So as a counter, 3D printing has a lot of features that the current technology is not up to the level of our imagination. The technology is not there. Especially the cheapest 3D printers are not reliable, by most accounts. The quality of the products and the manufacturing is really mediocre. It takes time to print even smaller pieces. It can go up to five, six hours for a small piece. The quality of surface can be really very mediocre, you can see the rough lines of the layers on the product.

The second limitation will be a limitation of personal fabrication. Not 3D printing, but really personal fabrication. At some industries, they already regulate it. Aerospace or automotive, aircraft or a car, you will never be able to print at home. You will be putting the public at risk. Especially in terms of primary structures. Structures that support and protect the passengers, you won't ever be able to do that.

The second point is obviously the scale economy; scale economies will always be there. For non-customized products, for that, mass production will always be the production of choice. For large commodity products, at least for the moment, this manufacturing is not the first choice. However, for small numbers of customized products though, the printing production is the best choice.

C. AUSTIN FITTS: Where I see it now making a huge difference is particularly for businesses, and even small businesses. If you want to build a prototype and try something it really does reduce the cost of what I call "messing around."

ONAT EKINCI: Well it is coming through more parts production also. There is movement in that direction, but it's still in prototyping phase. Of course there is a photo optimization point for the number of parts to be produced. To judge how much 3D printing is an advantage versus other processes. A definite answer on the number of products is very difficult, because it all depends on dimensions, context, and materials of the product. So it's difficult to evaluate exactly the number of parts to be produced by 3D printing.

But still, as the dental crowns or hearing aids in the medical industry, it can be an advantage if the parts are very, very customized. There is that side.

C. AUSTIN FITTS: Right. If you've ever waited a month for a crown, you know what a big difference it can make. Well, let's go a little bit into the history. Because in fact, you know, 3D printing has been around for quite some time. It's just now that it's starting to reach a point where it excites our imagination of what's possible. So, let's go back and look at the history.

ONAT EKINCI: All right, actually 3D printing history is older than most of us will think. It started in 1987, the first 3D systems were launched, and they were put into market. In 1990, there were other stereolithography systems offered by EOS, a German company. In 1991, strategists launched a different printer model through the Provision Modeling. So it has quite a history. These companies were in the market for quite a long time. Equally important will be the work of Neil Gershenfeld, head of MIT's Center for Bits and Atoms. He and his colleagues were real pioneers actually; they launched the first initiative on Fab Lab.

Fab Lab basically is a model lab that could be launched cheaply and quickly to provide basic manufacturing capabilities. People around the world, like people in Africa, these were actually the first maker spaces and hacker spaces. They had some basic components such as laser cutters, electronic design and so on. Of course, they had 3D printers. If you read Gershenfeld's articles from the 1990s, and his book that was published in 2004, he was already talking about most of the elements they are discussing today. Most of the elements that are in media today, he knew all about years ago. So it's just recently that it all came out to the media.

Right now we can sum up the evolution of 3D printing in three stages. The first is the control of shape. We are still in this stage. 3D printing can produce complex shapes, curves, and hollows. Complicated shapes. Best products from 3D with respect to the manufacturing or such processes. Especially complicated interior shapes. It's an ideal process for 3D printing. So this is the stage we are in right now. We are slowly going towards "control" over "composition." It will be combining different materials.

Right now, we are beginning to enter this stage. We can combine different materials with different colors and different shades of colors, like using different materials to print different qualities. Engineering qualities are still not in a desirable state. It's too early to talk about it. So this is a big possibility. You can mix different materials with different engineering qualities. So, let's say one's stronger and one's tougher. We can then optimize the final structure.

Other points will be electronics, because right now you're assembling all the electronic products, you're adding circuits and semiconductor circuits and so on. So we have the product of two different electronics. With 3D printing we can always combine different conductor and nonconductor materials and we can be more creative and create more efficient circuits. So this is for control over composition.

The third stage will be control over behavior. With this you will be able to create integrated, active systems that can sense and react and compute and behave. So we can create smart materials, which can give feedback, learn, and think, and provide structures or machine structures, circuits, and sensors embedded in mechanical structures and so on, without a separate assembly stage, like blood vessels integrated in muscles.

C. AUSTIN FITTS: I was reading an article last night by a professor from Maine who kept talking about printing out robots. His imagination was pretty far in the future.

ONAT EKINCI: Right. Right now, there are robots built with smart materials. They are not 3D printed, but it will go there in the future. You are not there, but the robot designs are there. It's possible. Then of course the very last stage, the ideal stage, will be a natural composition evolution. It will be creation of new life, creating live tissues out of cells. It's already been done by Organovo. So really creating new life systems with intricate blood and muscle structures, we hope will be possible in the future. So this was a brief introduction of the past of 3D printing.

"It will be creation of new life, creating live tissues out of cells. It's already been done by Organovo."

C. AUSTIN FITTS: Before we go on, I wanted to mention and I'll put up a link, in a recent article by Gershenfeld that we actually had up on the blog, I think 3D printing is an example, but in many respects it may not even be the most important example. I just think it's the one that's captured the popular imagination.

One of the things he says is what's happening is we're approaching a time when a lot of these technologies that we've been working on for decades are reaching the point where the speed and the cost at which we can convert bits to atoms and back into bits is speeding up. Part of which, I think, is the materials used. That has dramatic economic impacts as well, because the faster you can go from bits to atoms to bits, the less money you need to spend financing inventory. Or the easier a lot of the economic issues, particularly for businesses, change.

So I think of 3D printing as an example of this, but the profound change that's sort of upon us is the speed and the cost of going from bits to atoms to bits. That's a great point that he made. I'll have that article up on the blog post.

ONAT EKINCI: I would say it can be a big advantage for Amazon, for example, for their warehouse instead of having huge inventories, for many of the products they have, they can just print many of the—like books are done today. Printing on demand.

C. AUSTIN FITTS: Really? Yes.

ONAT EKINCI: So there's a parallel definitely in that direction. Now I'll go to the overview of 3D printing ecosystems?

C. AUSTIN FITTS: Yes, and I just have to brag on your PowerPoint. Onat did a series of briefings with me and then compiled them into a PowerPoint, which you can link to in PDF form up on the blog. It might help to look at that as we're following around, because we walked through the whole ecosystem and I think it's very valuable. So make sure you check out that PowerPoint. You may want to dive into the ecosystem part as we're talking.

ONAT EKINCI: So I have my presentation open about the 3D printing ecosystem and I am on slide three. I'll present the whole ecosystem of 3D printing. Ecosystems really help us to make a parallel, so we have a technological ecosystem similar to a natural one. It really emphasizes the interaction between different subdomains forming the ecosystem. There's the 3D printers, 3D scanners, 3D CAD software and the different technologies, different technological components are forming these domains. It helps us to better understand, to holistically understand what's going on in the industry instead of just focusing on 3D printing. We have to consider all the other factors in this ecosystem, like scanners and community.

So here are 3D printers, 3D scanners, 3D CAD software, reverse engineering software, and community. We'll go more into depth on this. Basically what everyone is talking about, or mostly in the media, is 3D printers, but there are also 3D scanners, which are as important, because what you print, especially in industry, you have to inspect, you have to measure. So, 3D scanners are very important in that sense. Also if you're an artist, you want to make your model by your hands, then scan it and then put the scanned file into a software that will produce a file suitable for 3D printing. So there's also that advantage of 3D scanners that is the reverse engineering. Where you scan your model to be able to print afterwards.

There is the 3D CAD software, which is very important, where you can build your own models and then transform your files to be able to 3D print them. So the capability of your 3D CAD software is also very important.

C. Austin Fitts: I wanted to just say, since you and I have been talking, I can't tell you how many people I've run into, both in a business and personal capacity, who keep telling me that both the cost of the CAD software has come down so far and the quality has so improved that it's almost like we're hitting a critical mass on CAD software, which has been around for decades. Something's happening where I think so many people, including young people, can learn how to use it and a lot of it is the economics. It's just economics and so it's more accessible and more people are using it. That is part of the dynamic of what we're experiencing.

Onat Ekinci: Exactly. There are free CAD softwares now.

C. Austin Fitts: Really?

ONAT EKINCI: Yes. So, it's getting very popular. You don't have to have any funding, you can just go on the Internet and—

C. AUSTIN FITTS: 20 years ago, what would it cost to buy some really good CAD software? Do you know?

ONAT EKINCI: Well, it would be probably tens of thousands for a good software.

C. AUSTIN FITTS: And today, what does it cost to buy some good CAD software?

ONAT EKINCI: Well, it really depends on what you want to do. A good one like SolidWorks is about $4,000 for engineers. There are many modules in that. If you are more of an artistic side, there's SketchUp, which is not free anymore. It was free until last year, but I think it will cost like $30 per month. There's also Tinkercad, which is newly free. So I think it really all depends on what you want to do. But SolidWorks, I will say, will be suitable for most engineering applications, and it's around $4,000.

C. AUSTIN FITTS: Which for small businesses, is accessible, whereas $20,000 or $30,000 might not be.

ONAT EKINCI: Exactly. It has many, many modules for engineering and offices. It's not only drawing but there are many other capabilities it can have. Then there is also the reverse engineering software like Geomagic, Beautify, Capture and Catch 123D. With these, you transform your point clouds into models that you are going to print. They offer another layer of capability upon the 3D CAD software. It can basically transform whatever you scan into a model to be printed.

Lastly there are communities like Shapeways that will help you. There are many parts communities, but in general you can share your files and share your models, and then people can download them into their own computers and print them. Or you can upload your model into the right side of, let's say Shapeways, and then people cannot download your model, but Shapeways can print it for other people who are interested in having the object in their hands. These are the communities. So maybe —

C. Austin Fitts: I have to say, when I saw your list of the communities in that PowerPoint, I was astonished. How long has it been since these groups have come up? Is it just recently?

Onat Ekinci: Many of them are recent, the last two or three years. But there are so many of them right now and it's really amazing for people in the industry. It's just amazing how this just exploded in a short amount of time. They don't have the same quality, all of them. It really depends on what you want to do again.

"There are so many of them right now and it's really amazing for people in the industry. It's just amazing how this just exploded in a short amount of time."

C. Austin Fitts: Right.

Onat Ekinci: So maybe I will go through some of these subdomains, 3D scanners, for example.

C. Austin Fitts: Yes. Please.

Onat Ekinci: If I go to the 3D scanner slide, which is slide 43, I have this 3D scanner ecosystem. I classified this according to industrial high-end scanners to consumer low-end scanners. They could have other kinds of technological classifications, but this is easier to understand. On the high-end side, there is Lidar by Nikon, which is for use in the aircraft industry. It's a huge scanner, which can measure a whole fuselage. It costs about half a million dollars.

Then we have portable arms structures like scanners, which are more in the medium range. They can measure the jigs on fixtures. It's an asset to industrial accuracy. They're offered by Steinbichler in Germany. Structures like these are basically in hands of Germans, and they're also from German companies. Then there's the consumer side in scanners.

There are new scanners like MakerBot Digitizer. Much smaller, and accuracy is much less than with the portable arms and such. Then at the end there is the consumer grade scanners. Any smart phone can be used as a 3D scanner.

C. Austin Fitts: That's quite amazing to me that we could someday be in a world where your smart phone can reverse engineer anything and then you can print it out on your 3D printer.

Onat Ekinci: Well this is amazing for anyone in the industry. It just ran so fast. Basically you can take the photos of your objects. There is Catch 123 application from Autodesk, which is free. You can download the app in your iPad or iPhone, or any other smart phone. You take photos, which are 2D, or two-dimensional. So the software of Autodesk, they basically stitch the images to form a 3D model, or a 3D point cloud. You can have a 3D model of your cat and then print it. It's really, really very nice.

Basically this technology existed, and has been in industries for many, many years. There was industrial photogrammetry and it's still much more accurate. Still we are seeing that the consumer side is getting heavier and heavier and they are going there again. The accuracy is not there, but you can easily make some artistic models by just taking the photos of your work. So it's going there and the software is free. You only have to go to the site of Autodesk to be able to download.

But again, in a nutshell, photogrammetry just always existed. On the Autodesk site, they also have a database where you can download your model and share with other people. So this is also becoming a community. Also there are open source options, even today. You don't even have to use Autodesk's Catch 123D or other; 3D Capture is also another alternative. But there is also a free, even a freer alternative, where you can use open source software to do all these things so you won't have to use the software of Autodesk. If you are geek enough, you can really play around with algorithms and create your own software. You won't have the limits of Autodesk software, such as the number of photos or relatively low resolution photos. So the sky is the limit.

So this is for scanners. I'm going to my slide about CAD software, CAD and CAE. Slide number 100. CAD is basically computer-aided drawing, and CAE is computer-aided engineering and CAM is computer-aided manufacturing. As you see here, there are many kinds of CAD software on the market. Again, classified from industrial to consumer. We have these high-end models such as CATIA, NX, or Creo. With which you can do anything you want.

You can combine, you can draw your parts, you can do engineering analysis, and you can prepare your files for manufacturing on machining or other sheet metals forming, molding techniques. It's really a complete system, which can cost at the very bottom up to $30,000 and go up to, depending on the number of modules, $70,000. So it's really very high end.

Then there is CAD and CAE software such as SolidWorks and Autodesk. Basically, SolidWorks also belongs to the same company that distributes CATIA, but it only costs like $4,000 or $5,000, depending on modules. You can again do engineering analysis. It is not as advanced as CATIA or NX, but still it will do most of the jobs. Then, as you mentioned, we are going more and more consumer low-end products like Tinkercad. I guess it is about $20 or $30 per month. Before it was free, but now it has been bought by Autodesk. Then there's free CAD, and there are other free CAD softwares. They're only for drawing, though. There is no engineering. If you're on the artistic side, it will work very fine. Even for very simple products it will work fine.

If you go to slide number 100, for example, with Autodesk you can do injection molding simulation. They have a module called *Moldflow.* It can do design optimization. Actually it can change the parameters of your model and you can optimize your model according to the qualities you want to have on your model. If you go to slide 106, you have Google SketchUp. It's been Google until last year, now it's been bought by Trimble. I don't think they are free right now. It's Trimble Sketchup. My neighbors designed their own house on Google SketchUp. It has many, many drawing capabilities. There is Tinkercad, again, more on the mature side, but it offers many basic capabilities you want to have on your drawing side.

Now I am passing to the 3D printing communities. This is slide number 109. So 3D printing services are, again, very diverse. Here also there is the… I want to say industrial, but on the high end and low end side there are 3D printing services with no model downloads, such as Shapeways, *Sculpteo*, or Layer By Layer. They're more, I would classify as high end because your models are precious for you. You don't want to share them with other people. You just want to give the possibility of printing them through Shapeways so that other people can order them, but you don't share the models.

There are also other services, such as can be found on Cubify, where you can share and the users can also download your models. So you have a portion. There's Thingiverse where people, again, can download your models and print them on their 3D printers at home. So there you give complete freedom for people to use your own files. Unfortunately the cost also lowers when you do that.

C. Austin Fitts: Sorry, what did you say, Onat? I didn't hear it.

Onat Ekinci: You can always share your models with people freely. In general, people doing this, like their models, are of not-so-great quality. The freer the model is, the quality gets a little bit downgraded. Then there are other sites like GrabCAD, which has become really big, and they're based in Boston. You can upload your models and download other people's models. There are models done in every kind of software, such as SolidWorks, Autodesk, CATIA, and others. There's a huge range of people.

There are professional engineers sharing their models, there are amateur students sharing their models. You can obtain many software models for basically free. It's a great sharing site. I use some of these files in my work for testing the capabilities of software. So it's a very valuable design. There are also metasearch engines for 3D printable files, such as Yeggi, so we can make a general search about any kind of file.

So if you to go slide number 111, you can see that here is Cubify free files and the quality is really not that desirable. In Shapeways, the quality of models gets really, really high because the models are not shared. In slide number 113, it's Layer by Layer, they give a guarantee. Again, you can't download the model, but they will print them for you. This guarantee is interesting because not every file can be printed. This is a good glimpse of the present capabilities of 3D printers. They have an additional printable to guarantee they verify all the downloaded files to see if they're actually printable. So this is also important.

So in slide 118, there is Amazon offering 3D printing and manufacturing products with 3D printers, and 3D printing materials. You have all kinds of possibilities. They have an option for 3D printing. Recently, eBay also has an app to be able to print relatively simple parts on 3D printing. So this was for the general ecosystem, apart from 3D printers. So I guess we can go towards 3D printers' downside.

C. Austin Fitts: Okay.

Onat Ekinci: So if we go to our slide number six, I made a classification of 3D printers. This I followed the ASTM 42 classifications, very recent standards. These are representative companies. The list is not exhaustive. There are different classes of 3D printing. In the media again, we always hear about 3D printing, but there are many different kinds of 3D printing. The most popular one, because their printers are cheaper in this category, is material extrusion like Stratasys' model Mojo, they all belong to this category. Then there is material jetting from Stratasys connects to the system's project. A higher quality class of 3D printing, there's binder jetting from ExOne and Voxeljet from 3D systems recently. Then we have vat photopolymerization, which is basically cinematography from 3D systems. Lastly there's powder bed fusion, or laser stenciling from EOS in Germany and 3D systems.

"In the media again, we always hear about 3D printing, but there are many different kinds of 3D printing."

C. Austin Fitts: Okay. So let me go over this again. It's material extrusion, material jetting, binder jetting, vat photopolymerization, and powder bed fusion.

ONAT EKINCI: Yes.

C. AUSTIN FITTS: Okay. I'm ready to go.

ONAT EKINCI: If we go to slide number seven, this is material extrusion. Basically you extrude your material with three nozzles, and the extrusion nozzles build a platform layer by layer. Either your platform or your head moves and inserts the Z plane. The platform of your printer can also move in the X-Y plane. So when a layer is finished, either the build platform moves down or up or the print head and another layer starts to be created. So this is the basic, the most common, popular 3D printing class.

If you go to slide eight, this is the most popular process. The first material extrusion process was patented by Stratasys, and they call it fused deposition modeling. Their printers, before they bought MakerBot, ranged from $10,000 to $500,000. So there's a big range. Stratasys' cheapest model is $10,000.

Then there are other companies, if you go to slide nine, like MakerBot. They've been recently bought by Stratasys. Their replicator costs only $2,200. So the advantage obviously is designed for consumers, not hobbyists, because they closed their open source structure. So it's not very fun to use for hobbies because they went proprietary. The disadvantage of this and other desktop 3D printers right now is their products can be variable. It will probably depend also on the context of what you want to print. You can always see those rough lines on a product, even though the resolution is getting lower and lower by the day. When they started, it was 0.5 millimeters, and now it's down to 100 microns. It's going in a good direction.

If you go to slide 10, we have the advantages of personal desktop printers. Obviously they are cheap enough for mass consumption. They are ideal for prototypes and ideal for homes, offices, and classrooms for making Maker Movement in general, and I will add there is much out there that is open source.

The disadvantages will be (this is also valid for other class of 3D printers) you have to buy the printing material from the manufacturer as you will buy cartridges for your inkjet printer. It's like Gillette's razor blade model. They give the blade to you, but razors cost a lot.

C. Austin Fitts: I know, when I first saw the prices, I said, "Oh, and I thought my color printer was bad."

Onat Ekinci: It's very similar to that, actually.

C. Austin Fitts: Yes. It's very expensive.

Onat Ekinci: So your investment is higher and most of the time will be higher than expected, especially if you print a lot. The other problem is the need for material standardization. Everyone has materials these days. There are no standards for item materials or processes. Everyone is doing something. It is still in a very fragmented state. For material extrusion, the materials must be plastic because of heating requirements, so you can't have metals, for example.

Lastly, layered properties will be high, and your layered quality will be high, but the layer-by-layer quality will be lowered, because you are adding your layers on top of each other, and that lowers the quality of the whole printout. I'll go quickly to material jetting. It is on slide 16. I put some links about material extrusion here, so people interested in this can go to those sites.

Material jetting is the process where the 3D printer is like an inkjet head, and it selectively deposits the material like in inkjet printers. The company started this in Israel. They used a similar structure to inkjet printers and then the layers actually are with UV light.

C. Austin Fitts: That's ultraviolet light?

Onat Ekinci: Yes.

C. Austin Fitts: Okay.

ONAT EKINCI: The main advantage of this, if you go to slide number 18, is the resolution is lower than the material extrusion, so the surface quality is better. You can go down to 16 micrometers. It's very, very good. The products are much smoother. You can print very fine features and you can use different kinds of materials, but again, no metals is important. Again, stuck to plastics because of heating requirements. Prices are much higher. The charge for these models is $150,000 still.

Another disadvantage is that there is no high performance or engineering materials. This will be also true for most of the 3D printing systems using material extrusion. You don't have high strength materials that could be used. Even secondary structures for aerospace, the material strength is not enough for material jetting.

I am going to binder jetting now. It's slide number 21. In this method, this class of 3D printing, a liquid binder is deposited through inkjet nozzles, and some powder materials in a powder bed. Then, again, the same principle: either lower your platform or raise it. You solidify layer by layer. You basically glue your layers of powder material.

C. AUSTIN FITTS: What's the powder material made from?

ONAT EKINCI: Well, it really depends on the company. It can be made from plastics or metals. ExOne, for example, always have sand, as I mentioned, sand molds. You can use specialty sands. You can also use metal polymers and plastics.

C. AUSTIN FITTS: So you can make them strong?

ONAT EKINCI: A portion for defense materials. This system was originally developed by MIT. Right now, 3D Systems and ExOne, are using the licensed technology from MIT. So if you go to slide 23 on ExOne, they can, for example, use stainless steel, but there is always a secondary cycle here for putting the binder out. It's a little bit more complicated. ExOne models are also used in Shapeways, a community printing service, basically, where they can print your models in metal using ExOne's machines.

Then on slide number 24, they have sand systems. These systems are used for sand molds and to model for oil and gas customers. It's not only for prototypes, and it can basically make products with this technology. But again, I must add, this is at a much higher price. Like ExOne, the simplest machine starts from $150,000. It's really expensive.

There are other kinds of binder jetting companies. If you go to slide 26, there is ExOne's competitor, Voxeljet, which uses a very similar kind of technology. There are also other existing companies. Many of these companies are basically in Germany. It's like there is a German policy, like a government policy, probably to direct companies, which is also very promising. It's an industrial side rather than consumer side, and you don't hear about these companies as much anymore in the media, of course. Then there is the Swedish companies which use electron beams, such as Arcam, to make especially prosthetic limbs. I have other examples of Voxeljet and I can put some up links again about ExOne for interested people to go to.

"It's an industrial side rather than consumer side, and you don't hear about these companies as much anymore in the media, of course."

Then there is stereolithography and photopolymerization. In this, you basically cure a photopolymer with a light, in other words, you cure a material using only an ultraviolet light. They were commercialized by 3D systems a long time ago, as I told you. The quality is much higher than material extrusion processes, because they're using light and the resolution is much lower so, the quality is much better. Slide number 30 has some of the industrial applications using polymers for these products.

On slide number 31 there is an interesting development. There's a company, which started from Kickstarter, and they launched a desktop machine that will be using the same technology from 3D Systems. This will be a MakerBot counterpart, but with higher resolution, higher quality, and are a little bit pricier: $2,030, compared to $2,200. But they've been sued by 3D Systems, and they were using 3D System's license for paying royalties to them.

The disadvantage of this technology is, again, the materials cost a lot. About $175 to $250 per program, with respect to plastics for injection molding, which cost two or three dollars per program. It's a huge, huge material cost. They cannot be as strong as their counterpart injection molding, these plastics, and some of them can be toxic. It depends on how safe it will be to use this technology. The workshop, you have to have a good natural ecosystem. Again, there is no metals that you can use with this system, for the time being.

The last technology is the powder bed fusions on slide number 34. This is a similar technology. In this case, you are mounting your material and it's solidifying. Metals can be used, like steel, aluminum, and titanium and you can obtain more uniform part characteristics, which is like the casting. Again, it depends on what your building. If your part is too big, it cannot be done in casting. It all depends on what your part is, what you are trying to do. If your part is too big, it will take time to cool off and the parts characteristics in the end will not be as uniform.

C. Austin Fitts: Is it just the Germans who do this? Or do any of the Americans do it?

Onat Ekinci: American companies do. I don't remember which ones right now, but of course it's really more on the German side.

C. Austin Fitts: The Germans who make it? Yes.

Onat Ekinci: They also have a history on this. They've been doing this for a long time. The materials or metals that can be used in this are also expensive with respect to conventional materials. So, the material part is a bottleneck, and cooling, again, is the problem after power bed fusion, because if you have to wait for the material to cool, then it will take time. Even if your process is fast, you will still have to wait for cooling so that you can do the second step. And that is it for the 3D printers.

C. Austin Fitts: Yes. That's fascinating. I haven't seen one operate yet. I've seen a little one operate at the tech shop, but I haven't seen the big ones operate. There are lots of videos on YouTube where you can watch them operate. So, I've watched plenty of videos. Okay. Well, so tell us, what does this all mean?

ONAT EKINCI: Well, about the future, I will say, I have my list of negatives. Negatives and aspects of the 3D community for today. I don't want to finish with the negative aspects, so I'll start with those. So currently, as I said before, materials still are too expensive with respect to injection molding, if you're using plastic materials. Scan goes up to 50 to 100 times and standard ISO based on ASTM communities.

C. AUSTIN FITTS: If you could just explain what the ASTM and ISO are. Not everybody knows what they stand for.

ONAT EKINCI: So, ISO is International Standards Organization. It's a big organization, and ASTM is like the equivalent in the US where they standardize these processes and materials that are used in these processes so that you can judge the quality uniformly in every aspect of the process. They're very important. If you want to build an aircraft, for example, you want to be certified according to the organization's qualifications. Most of the time the standards are prepared by a committee of experts so when you use these standards your parts are really up to the standards of the industry you're in.

The other negative point I will say is about the intellectual property side is it concerns replication permission. With this technology, especially in scanners, people can take photos of sculptures and print them. Or if you displayed your work somewhere, people can, again, take photos and transfer them to point clouds and print them. So what about the copyright issues? It can create many headaches in the future.

The second issue about, again, intellectual property is even though 3D printing is largely linked to hacker space or Maker Movement, you should not forget that many technologies are covered by patents from established companies such as 3D Systems and Stratasys. I gave you before the example of Formlab, which was financed by Kickstarter. They were sued by 3D systems and they finally reached a settlement for paying royalties. So we have to be careful with our initiatives because of these patenting issues.

The third issue about intellectual property is that you have to be careful with intellectual property. We have to be careful with our open source endeavors and try not to be exploited because some of the initially open source companies, such as MakerBot, have been bought by Stratasys for $400 million. So all those files got transferred to be shared with people now to the open community that MakerBot sprang from. They basically used, in the first stages of their company, all open source projects, such as Arduino, Reprap or other open sources. This is an important point, not to get exploited by the open software, the open source side of 3D printing.

So that was the negative parts, now the positive parts about the future. Conceptually, 3D printing offers three possibilities for the future. But we still have to think holistically; we have to think of 3D printing in a context of ecosystems of manufacturing. 3D printing is in context of other conventional processes, machines, and materials such as laser cutters, C&T machines, and control systems. They'll be complementary to all the ecosystems manufacturing that still exist.

An interesting point will be hybrid technology. There will probably be more applications of 3D printing in the assembly side. The problem with 3D printing combined with machining, classical machine technologies, is it's actually already being done by a company called Matsuura in Japan. Their machine can 3D print. It can read it, center, and mill at the same time in the same machine.

C. AUSTIN FITTS: So let me ask a question, Onat, because I live in a part of the country where the auto parts business is enormous, but we still have a lot of small machine shops. Could this technology get us to the point where the local machine shop is making a lot of the parts for the farm equipment and the cars and the appliances? Is that possible?

ONAT EKINCI: Well, it's really possible, I would say, but again, I'm on the cautious side. It would all depend on the parts they want to make. The parts, honestly, if it will be millimeters, they can do it very easily with local printers. But if you go to the cylinders of an engine, there, you would have much lower tolerances. They would have to be done on the high-end side of 3D printers. So it will all depend on the application. Yes, there is definitely a movement in that direction. But it will, again, depend on what your application will be.

Another thing in direction will be the materials side, as I had mentioned before. The smart, intelligent structures done by smart materials, where you can embed materials that you can react with. They have sensors or an actuation and they use small cylinders or mechanisms. Instead of building them, assembling them from mechanical parts, you will just be able to print them, hopefully, in the future.

> **"Instead of building them, assembling them from mechanical parts, you will just be able to print them, hopefully, in the future."**

Another interesting thing will be new applications. We definitely need new applications. No one knows how this will go. We don't know exactly what the applications will be in this. So I guess we just have to ask the inventors of computer science, 30, 40 years ago about the daily use of the software architectures, they would not be able to describe on the software applications that we have today. So it's difficult to predict about new applications. It will probably be more on a selectable electronics side, where you won't use big parts for personal fabrication, again, where you won't need really big pieces and you could build some customized electronics at home, depending on your desires or need.

Lastly, of course, this is the ideal: to print life out of printers, out of cells. As I mentioned, Organovo can only build tissues out of cells to be used for testing drugs. So it's in a very rudimentary stage right now. Hopefully this will also be used in the future so they will be able to create organs cell by cell. They could print organs. So the future of tissue engineering could depend on printing sheets of cardiac tissues.

C. Austin Fitts: I was out here in California, and I came back a year or two ago after Organovo first started. I was telling someone about it, and they said, "Oh, that's—" they didn't believe me. They thought I was making it up. Just then they turned on their television set and there was a TV show about somebody getting a kidney transplant, and they had a 3D printer that was printing out a new kidney. So I said, "Well, Hollywood's getting you ready."

ONAT EKINCI: Exactly. They are going in that direction. So we can hopefully renew and patch the tissues in our hearts and in our kidneys. For an ideal situation, they can use Neil Gershenfeld's words, you will transition from personal fabrication to the fabrication of a person. So that's the optimal space.

C. AUSTIN FITTS: I'll go one with a kidney. I don't think they can fabricate a person.

ONAT EKINCI: Well, even just some spare parts.

C. AUSTIN FITTS: Right. So tell us, Onat, where can people learn more about 3D printing? If they've listened to this, if they've gone through your PowerPoint, where do they find more information?

ONAT EKINCI: Yes. The main problem with 3D printing right now is that there are not so many references, especially in academia, because it's very, very new. There are no standards, I guess. It's not easy for professors to teach this. There are a couple of books, such as *Makers* from Chris Anderson. There's *Fab* from Neil Gershenfeld, as I mentioned. They're very interesting, first talking with an introduction to the field. The *Maker* magazines all over the place. They're very fond of it, it's very well designed. There is the *Wired* magazine, which frequently talks about 3D printing issues.

There are websites, such as Instructables. This is not one on 3D printing, but where better technology is the concern in the Maker Movement. There are blogs like TechCrunch, Ars Technica and Engadget, where you can find information about new developments in the field. Of course, lastly there is the Kickstarter website itself, which is always good to check to see who is doing what. Because there, it's advancing so fast, no one can follow what's going on exactly, not even the media. So you can always use the Kickstarter site.

C. AUSTIN FITTS: Okay. Tell us how we keep up with you. How do we find you? How do we contact you? Just describe your blog a little bit.

ONAT EKINCI: I have my website, innovationrex.com. I am doing resource consultancy for different companies right now, so if people are interested, of course I'm open to the contact. They'll probably put my email on the website.

C. AUSTIN FITTS: I'll put it up on subscriber links.

ONAT EKINCI: Okay.

C. AUSTIN FITTS: Okay. Well, Onat, this has been an incredibly useful process, learning about 3D printing from you. When you look at the media, I think, of all the different kinds of fabrication technology, this is the one that is the easiest for the layperson to understand. Of course, the price point is coming down on the little ones, so it's captured our imagination, and it's clearly being promoted a lot by the media. But finding out the real deal on it is another whole process. You've done an incredible job of helping me understand not just what they are, but how they fit into a much broader 3D ecosystem. This has been invaluable.

ONAT EKINCI: Thank you very much.

C. AUSTIN FITTS: I'm hoping to get you back on The Solari Report because there's a lot more to talk about. One of the ones I'm most interested in is the composite materials, because part of what's happening is the revolution in materials as well. So with that, I can't thank you enough for being on The Solari Report, and I want you to promise us all you'll come back.

ONAT EKINCI: Thank you. I promise.

C. AUSTIN FITTS: Okay. You have a great day.

ONAT EKINCI: You too.