Transcript

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3D Printing and the Next Industrial Revolution

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David Grossman

Welcome to Chatham House for what I hope will be a fascinating discussion. My name is David Grossman, I am the technology editor for the BBC's Newsnight programme and I would say there are maybe three different types of technology that I get to see in my day job. There's the 'so what' sort of technology that you don't really care about. There's the 'that's nice' technology and I'd put the iWatch in there, the Apple iWatch. Then there's a third sort of technology that I would say makes you change what you eat. It makes you exercise more and give up drinking in the desperate hope that you can live long enough to see what this technology will become. I think tonight's technology is one of those.

It's definitely a bran flakes and exercise bike technology. 3D printing and the next industrial revolution, if I could first introduce our distinguished panel starting over on the right, Ludmila Struikova is a senior research associate and a senior teaching fellow in the Department of Management Science and Innovation at University College London. She's a specialist in business, economic and legal issues related to 3D printing. To her right is Jonathan Rowley, he's the design director of Digits2Widgets. It's a Camden Town based 3D printing studio and Jonathan is also a qualified architect.

Next to him is Jon Fidler, who's the founder of Modla. It's a 3D printing design consultancy that was launched back in 2012, but you have been in the area of 3D printing and manufacture for a lot longer than that. And finally Professor Justin Cobb, chair of Orthopaedic Surgery at the Department of Surgery & Cancer at Imperial College London pioneering computer assisted and robotic surgery for the past 15 years. I think we're going to kick off tonight with all of our panel saying their piece. I think we're starting with Jon.

Jon Fidler

Should I stand up for this maybe, perhaps, a bit more comfortable. Hi guys. My name is Jon Fidler.

David Grossman

Just before you kick off Jon, sorry, can we just say, this is on the record tonight. So I don't know why it wouldn't be, but there we go, and if you want to tweet, there's #CHevents and if you could put your phones on silent before Jon starts, thank you very much.

Jon Fidler

Hi, I'm Jon Fidler, as discussed, I've been in the world of 3D printing now for about 10 years. First came across it at my time at Bournemouth University where I was studying design engineering, used a process called FDM there, fell in love with the technologies and then went on to very much explore them. I've done a masters in technologies at De Montfort and then went to kind of set up Modla around that. So yes, there are my Twitter handles at the bottom, so do feel free to tweet me during the talk.

So Modla, who are we, what do we do? We are a design consultancy specializing in the creative industries, working in the fields of fashion, product design, architecture, arts and many others also. The types of services we provide, 3D design to 3D scanning,

visualizations and renders, you can see here and also in the field of additive manufacture as well. So, first of all, just so we clear up how do the processes work, how many of you guys here have used 3D printing before? Anybody? One of you, two, cool, so you understand it.

Okay, this all works basically, first of all we have our idea, so if I may be a fashion designer, I've come up with a shoe, I've got that idea. Now what do I do? Then next thing that we need to do is create our digital file. So everything revolves around our digital file. Now, we create that digital file in our 3D software, so at Modla we use software called SolidWorks. You can use AutoCAD, there's many different softwares that will output the file we need. Then once we've got our file, it will go into our machine, as you can see there, we've got the example of a car and there's lots of these digital technologies and that will build up our part layer by layer and then our part comes out the other end.

So really kind of nice streamlined process. If you had to do that with traditional methodologies you'd perhaps need to use thousands or hundreds of machines to do so. So just so you see, here's our, just an example of the Olympic Park that I done for the Olympics. So created the Olympic Stadium here using SolidWorks, you can see the detail that we can go into and then there's the finished 3D printed part. So the really great thing about these technologies that we can do really detailed, intricate parts. Also it allows us to kind of work in a number of different fields.

The technologies themselves, I'm sure Jonathan will mention as well in a minute, it very much, I think, splits down into two areas. As you'll see at the moment there's been a lot of talk about the technologies on the market, so we've got the lower cost machines and we've got the higher cost machines. Lower cost machines will cost around £1,300, but do be warned, they cannot do what the higher end machines can do, okay? These machines use lasers and so forth, a lot more kind of technology in them, a lot more advanced, so we can create much more kind of intricate designs and more complex structures in this, so do be warned about that. I would go into more depth, so here we've just got some examples of some of the parts we made at Modla.

Up in the corner, see that's [indiscernible] we'll talk about in a minute and then some more detailed kind of structures there. So first of all I want to just talk about the two different areas that we can use 3D printing. First of all, for prototyping. Now this is a project that I've worked on, one of my companies, it's called Naturebytes. This is where we've used the lower cost machine to produce prototypes for our project. The great thing about it, here we can see over here is the 3D printed part; we designed it in our 3D CAD software. What this is, is a camera trap, we've been funded by Raspberry Pi Foundation and we've developed a wildlife camera trap kit that we'll give to kids and children to inspire them to get in contact with nature.

So we designed the housing using 3D printing and the great thing about these technologies, using one of these printers, £1,300, is that we can create this kind of, this camera trap case and prototype it. The great thing about it is it costs us, you know one of these units would cost me about £3 to produce. Using traditional methodologies, you know, other methods could cost up to £100. The time as well, I can churn out one of these, it will take seven hours on my lower cost printer to make. As I say, if I was to go and use kind of more traditional methods, it will probably take me a lot longer time and

the digital process as well, that's quite an important factor. I can go back to my design and change it.

So once I've printed it, I can see if there's anything wrong and then I can just go back to it and modify it and change it. So it's that digital work frame, that's very much an important thing about these processes. The next one is direct manufacture. I'm going to speed through this because I don't know how much time I've got. So direct manufacture, what I mean by this is we can actually use 3D printing for our finished product. I'm using an example here, this is a work project I worked on with a shoe designer called Kerry Luft. She produced these beautiful high-heel shoes and the actual component of this, the high-heel itself is produced using 3D printing, a process called direct metal laser centring where the actual heel is being produced in titanium, which I'm sure we'll hear a bit about within our medical talk.

So here we go, the nice thing about it, she sends us our 2D drawing, we create the 2D drawing in our 3D CAD software, we can render that out with our 3D CAD software as well, so before we actually make it – because it can be pretty expensive to use this – we can render out something, we can send it across to our client and they can go, 'yes', 'no', make any alterations and then we can 3D print it. Now, the quite nice thing about this project also was the fact that we printed it on a kind of FDM machine and we could send it over to the workshops out in Italy and they could test it on the actual shoe and they can make any, if they made any changes they'd sand it down and go and then they'd send it back to us, we'd re-scan it and make those changes to the digital file and then it was printed, which is great.

So just a quite nice example of the materials that you can use, we can use with these technologies. Other uses, we can use it for indirect manufacture, so for producing tooling. We can use it to produce with investment casting, so we can produce a wax to be investment cast from, so used very much a lot within the jewellery industry. For jigs also, so yes, there's a lot of different applications. There's many more than this, but I wanted to keep it quite brief because I haven't got too much time.

So just some quite nice interesting areas where I've seen it being applied, prosthetics for children, so this is 3D printed on the same machine that I talked about earlier, the £1,200 one, would cost around $30 I think, so it's really cut the cost, but I think the nice thing about this project is, you know, it's a super-hero hand, so it really kind of tips it on its head about having a disability for the child and we can really create these quite intricate, nice, different shapes using it. Using 3D printing in space as well, they've sent up a machine to the space station, so been printing off part, I've actually got the wrench with me that they printed off there. So it's quite an interesting thing because the fact is we could take a printer with us to Mars on a mission and we wouldn't need to take loads of spare parts with us.

If anything goes wrong, we can just print the part off there and then. So it's really quite interesting for that application. Then quite an interesting one, where else could 3D printing be used? From my view of things, of seeing the technologies, now, a big problem is e-waste, you know, for instance in the, they say that there's expected to reach 93.5 million tonnes in 2016, that's e-waste, so stuff like our phones and iPads being chucked away. To put that into perspective, that's 93 million cars essentially, of waste, so that's

quite a lot. So maybe we could use these technologies to redesign products, so rather than chucking it away, we could have a 3D printer that could produce the spare parts, so therefore items could be reused.

As I say that, because I say spare parts because we wouldn't necessarily, the printers have their limitations in terms of sizes and everything that we can create, so maybe it's not kind of, it's not that effective to produce the whole thing, but it could be used in that manner. So I think I'm going to finish up there and then we can pass over to the next speaker, but thank you very much.

David Grossman

Thank you very much indeed Jon. Now Jonathan Rowley, design director of Digits2Widgets.

Jonathan Rowley

Great, good evening everybody, thank you for coming. My name is Jonathan Rowley, I'm the design director of Digits2Widgets and I've only been involved in 3D printing for about three and a half years. Before that I was a practicing architect in London, so in some ways, very different, but in other ways, I know how to make things, I know how to put things together and that's the beauty of an architectural education is that you can apply it across all sorts of different disciplines and then when you ally that to 3D printing, I have a very, very interesting and exciting working life.

Now, Digits2Widgets are industrial 3D printing bureau based in central London and we don't run the types of machines that Jon has been showing, which is what we call 'home printers', we run industrial equipment, which is rather more sophisticated in terms of the materials that they run and the geometries that are achievable. Now, on this opening slide, why I've put question marks after the title of this talk is that, I mean I was intrigued that this talk was entitled that way, as a statement. Now, I'm not certain that 3D printing is the next industrial revolution. I'm fairly confident that it will play a part in it, but there are also all sorts of other digital manufacturing technologies that can play a role in changing the way things are made.

I have something of a reputation within 3D printing of being negative about it. I don't see myself as negative, I see myself as critical and that's a very different thing. I try and look at what I'm being shown and assess whether or not it's any good. With apologies to the journalist on the panel, the media love nothing more than a 3D printing story because it relates to science fiction, it relates to technology, it relates to Apple, it relates to all of these things that we know and love and trust today and it appeals to our optimism and there's nothing wrong with that, but when I start reading statements like 3D printing will lead to the democratization of design, I mean that's gibberish.

It will allow a whole new section of people to have a go at starting to make things and starting to produce things, but to suggest that design was some kind of totalitarian discipline that nobody had access to before, if anyone is interested in making something, they can make it and this is just another tool which can be very useful. Certain brands of home printers have selling slogans like 'I can make anything with this machine', this is

just not the case. Some machines claim to print multi materials and when the general public hear that, they think, fantastic, there's a machine that prints me an object that's got a combination of glass and wood and plastic and electronics and this is wonderful.

It is not a multi material printer as you would understandably understand it. It's a blend of the same stuff. It's a digital material, very interesting in its own right, but to market it as a multi material printer is disingenuous. Then finally, if you read anything that tries to impress you with the fact that it is the world's first 3D printed whatever, you want to look very long and hard about it because if the fact, all that it's got going for it is the fact that it's been 3D printed, it's going to be deeply deficient in many other areas. I have a little theory that the reason why the general public are so keen to swallow all of these very exciting stories is that over the last 100 years in the developed world, the general public have lost all connection with how anything is made. They've got no idea.

100 years ago, if you lived in Northampton, they were making shoes there and it doesn't mean that everybody in Northampton was involved in making shoes, but they knew people who were, there was a factory in the heart of town that belched smoke, they saw raw materials going in and products coming out. They understood there was a process. People today have got no idea how anything is made. So when somebody tells them that very soon they'll be able to buy a box that they can have in their living room that can make them anything, that's a perfectly reasonable proposition. I've got no idea how everything is made now, so why not.

Now, my last bit of negativity, I want to focus on the famous 3D printed house. This was published in The Guardian last April, you know, a very august publication which the people should be able to trust. And they are showing images of this thing in China and they are saying that this technology will allow 10 complete houses to be printed in one day. If we look at that image, what's 3D printed on that are the walls and some sections of the structure beneath that roof. That is all that's 3D printed, that is a sheet metal roof, that is a cheap aluminium sliding door, this is a really lovely levelled site that somebody's had to dig up and pour concrete into.

It's just fantasy to suggest that 10 of those are desirable, one of them isn't desirable and that it can be achieved in a day. I mean it's really just a joke and the fact that anyone swallows this beggars belief in my eyes, but because it's 3D printed, it's magic and we should all be gasping and gagging at this prospect. Now, what is so difficult these days is you can read an awful lot about 3D printing, but it's very hard for people to actually see 3D printed objects, unless it's a little toy, it's very hard to see anything that's anywhere near a production object.

This is an example of something that we helped prototype by Ron Arad, he's a very experienced designer and he's not looking to 3D print a pair of glasses frames for the hell of it. He's using this technology for a purpose. He wants to produce a monolithic frame because any spectacle wearers in the audience know, that the hinge is where your glasses are going to break. So if this can be designed and produced all in one go, that will be beneficial. I actually have a pair of them here and so afterwards if anyone would like to handle them and even try them on, they should speak to me. So that is monolithic, printed all in one piece, it's designed and printed in the closed position.

This material has a memory, so that is [indiscernible], when you do that, it's not comfortable, when you let go, it does that and that means, it means self-closing isn't exciting, but that means that pressure is holding them onto your head. So these are damn good in their own right. The fact that they're 3D printed is academic. They have no hinge and they hang onto your head and those are two fantastic characteristics and these are what 3D printed objects ought to start to be looking like if it's going to be the third industrial revolution.

As I say, the material has properties, what we're illustrating here is a very simple project for a bird box that was originally suggested to be printed complete in its whole finished form. But because this stuff is flexible if you print it thin, it's been designed like a card model, so it's built and designed and printed in two flat sheets that are designed to fold and bend to create the finished form. This is designing with 3D printing and this is what people need to start to understand. It's not just shape making, it's not just making a shape on a computer and getting the machine to reproduce that, it's about understanding the materials that it can produce too, to make things better. The fact that this could be printed flat in two parts meant that we could produce many, many more of them much more cheaply; we weren't printing the fresh air within the box.

Now, this is a very spectacular fashion piece that we helped to produce. This was not printed all in one piece. This is made up of 110 different 3D printed feathers or CAD files of feathers and it's actually designed so that the base of each of the feathers, there is a ball and socket joint that allows them to be 360 degrees flexible. This thing is all articulated. It wasn't printed in that position, it was designed to be printed as elements that come together and that's fantastic. What really upsets me, and you can tell that there's upset in my voice, is that people expect the 3D printer to produce, to spit out the finished object. That is totally unrealistic in this day and age.

What you need to do is understand what you're trying to make and design it to make parts that you then put together. What's so beautiful about Jon's shoe project is that it's not making shoe manufacturers redundant, it's making shoes better. It's being sent to factories in Italy where craftsmen are still producing shoes, but there's a much more exciting heel that's gone on it. Then these are some 'fabrics' in inverted commas that we've developed. These are all printed in a single piece and I've also come some of these with me if you'd like to handle these afterwards.

They're effectively chain mail, but all designed digitally, printed and come out of the machine in one piece and there are certain flexible materials available these days that they are not that good. They're not very durable, they're not as flexible as you'd like. So what this demonstrates is if you want to produce something flexible, you can use it using the rigid material, but you design the flexibility into it. Now, just to finish off, the shoes on the left are what are being sold, or people are trying to sell to women these days, to ladies, because ladies love shoes, it's their way of getting ladies excited in 3D printing. And the story they tell is that ladies, you can print a new pair of shoes every night and wear a new pair of shoes every day, because what more does a lady want?

Now, this white stuff is a rigid, brittle plastic, these are clogs. This is a shoe shape produced in a material that might be fairly effective for the sole, if not terribly impact resistant, but that thing is hard and solid and is going to be extremely uncomfortable and

just totally non-viable. The other thing that they're quiet about is if you look just there you can see a little black line and what they've done is that they've epoxy resined a rubber sole onto the bottom of that so that you can actually get some traction off it and I'm sorry, but ladies may be excited about 3D printing a pair of shoes every day, but I don't think they'd be very excited about having to epoxy resin a sole onto the shoe before they go out every day.

The object on the right is also a shoe, but in my view, if 3D printing is going to be part of any kind of new manufacturing revolution, people need to start understanding the materials and the technology and start looking at designing things with that in mind, not copying shoe shapes, but re-imagining and re-designing the shapes based on the technology, based on the materials and based on an understanding of how forces work within a shoe. I don't discount a 3D printer being able to produce a very successful shoe one day, but it will not look like shoes as we currently know and love them and that's the end and somebody else can be positive now.

David Grossman

Thank you very much indeed Jonathan, maybe I shouldn't be eating bran flakes after all! That was a lot to think about. Professor Justin Cobb now, please, a bit more positive perhaps?

Justin Cobb

I think so. So I'm going to whizz you through a bit of my world in a few minutes. There is, in my world anyway, there's no more money, everybody knows that. Sorry, you can print more money, it's easy, but there's an unbelievable demand, if you'd have been in hospital with me this morning you'd have seen not unusually a lovely woman, actually she's the mother of someone my age, an 87 year old woman hobbling along on crutches and this is what we see. What you didn't realize was she was coming in to see her mother, okay, you know, don't think that the actuaries have got it right yet.

So there's no more money and there's a huge demand, in my world, of people wearing out. In Britain 200,000 hips and knees are replaced every year, each of them costing more than a car and the workforce, we just haven't had the industrial revolution, so John Chandley in 1960, in the 1960s was doing more operations a day than a National Health Service operating theatre and we haven't had the productivity revolution. So for me, I think, the post 3D revolution is going to be a technology up-skilling surgeons, getting everybody aligned, everyone's incentives aligned so there really will be a revolution in productivity and 3D printing is definitely going to be a part of that, I would say, absolutely positively.

As Jon and Jonathan mentioned already, you need imaging and if you can't both image and imagine what you want to do, there's no point in having a printer and this is putting things, putting little parts into someone's knee to allow, not a very big monolithic knee replacement, but just little parts instead… This is from Martin in the lab, he's able to take a CT scan and we can do the surgery beforehand. In this case re-aligning someone's knee, do exactly what we want beforehand because he's written the code to let us do it and in fact, not on this little video clip, but we can now actually grow organically the plates there,

so it's the right shape and thickness for each individual person. So that's a really exciting model.

We can look at deformity. We can take someone through the lab, make them walk, see where the loads are going in this rather deformed left leg that you see, and then design a procedure to allow that person to be put back together again. So with design, you need designers sitting, this is Simon Harris, writing the code to allow us to do things and if you haven't got that, you can't start, but with that, then really anything is achievable. A tiny bit of our devices, these bits of metal here, these are casts, castings, have been going on since the Bronze Age, really not much change in the casting, it is titanium, it's not bronze, but these are just bits of metal and these are, too many pictures, but these are pictures of two different sizes of conventional femoral stems.

The smaller one, this little one here is much better for the person. One little graph, the green line there is the elasticity, all of our skeletons are elastic. If you're running up stairs your femur is flexing by four or five millimetres, just running up stairs, your whole femur flexes. If you've got a stiff bit of metal in your bone, that bit doesn't flex and that not only restrains you, it stops you running, but it will also be a stress riser and actually maybe precipitate a fracture later in life. The red line there shows the hysteresis loop of the shorter stem which is definitely bit of progress, but it still casts too many [indiscernible].

But the 3D printing revolution is going to let us print and so this is actually, this is just a CAD file you see, even printing the CAD file, this is such a big file, the machine can't read it, you actually have to write programs to get the machine to read the file, to make something that is really organic. So this with a very thin layer for the interface with the bone, but inside that no more material is necessary to be strong enough until you're 120 years old, but not any stiffer than necessary.

Possibly beyond that is a whole world of new materials not [indiscernible] layer, but I think I'll maybe talk about that later on in the bar. Now onto the patient instruments, if you were in theatre with me this afternoon you'd have seen me having a lovely time operating on someone with instruments made by – this is a little spinout from the lab – this is because everything happens before the printer, you know. So Susanna who runs it, she actually designs the devices and then, actually Dee, he automates the designs, so they're going from one to automating for all of this, takes them a minute or two and that's the real revolution for us and here's Martin in the lab too.

Here's our EOS machine printing out and out of that build comes a little box printed with the patient's name on it and those are the little bits of polymer. If you don't like blood, close your eyes now, just for a couple of minutes, just five pictures. This was last week, this little jig fits on the outside, every single one of us here, the bumps on either side of our ankle are in individual places and these bumps, we use those to locate this little jig on the outside. This goes inside the body, fitting exactly on the body and just down at the very bottom there you see just here, this bit on the skin, on the outside, so very precise location allowing you to achieve exactly what you want… Too much blood.

You get the idea that these little bits of polymer, they cost probably £25, allow me to perform surgery, allow any surgeon to perform surgery with an accuracy that would take, you can't achieve that reliably, you just can't do it. So very quickly, this is a fellow who was

run over by a lawnmower in his childhood and so had this deformed right leg all his life long, bent and slightly bitter and cross person because of being sore and so using… This from a case a couple of years ago, allows us to achieve a level of precision that we simply couldn't, you couldn't do this, you really couldn't do this surgery without it.

I'll finish with a couple of pictures, this is the cheapest you'll ever see. These tiny bits of polymer, this is now costing about £1.50, that little bit of polymer locates on the femoral neck and this is for a hip, very accurately and so if you planned precisely, that tiny bit of polymer allows you to achieve it. I'll finish with this little, this is a rather stroppy trainee of mine called Adil and the Adil test is, if he can do it, he's a rather grumpy fellow, if he can do it and put this on accurately, it's good enough for general release. So here he is, he's putting this on and once that's there, with one single pin, no surgeon can do this operation wrong, where there's one extra accompaniment, you'll see as we just pan away, he's doing it blindfolded.

David Grossman

Thank you very much indeed Justin, fascinating, and I'm back on the bran flakes now. Finally Ludmila to discuss the legal and economic implications for 3D printing.

Ludmila Struikova

Well perhaps while I'm waiting for the screen to show my presentation I can introduce myself very briefly. Unlike Jonathan sitting here, I have a reputation of being a 3D printing enthusiast, so it's very, very hard for me to be critical about 3D printing. But I will start by presenting some of the issues, potential issues with 3D printing. So in the next six minutes I will try to squeeze in legal and economic aspects of 3D printing. I'll start with legal implications and when we talk about legal implications, the two elements that could be relevant to 3D printing are liability issues and intellectual property issues.

There is a LinkedIn group devoted to 3D printing and when people join this group they are asked to state what's their interest in 3D printing and quite a lot of people say, 'I'd like to print spare parts and toys.' So it seems to be very kind of interesting objects to print and indeed it seems like something which can be achieved and can be rather cheap with the help of 3D printing. So here's an example, a famous brand of pushchair, Bugaboo, if some of these small spare parts are broken, you will get a quote from Bugaboo for £250. So to replace these four parts it will cost £250.

It's also possible to go on online platform like [indiscernible] for example and to have these printed and sent to you for £25. So we do see the difference. The issue here is that is what is going to happen if this pushchair breaks down and what is even worse, if there was a kid inside and the kid was hurt, who is going to be liable? Is it going to be Bugaboo, the person who replaced the parts, the print maker? So far we don't have a definite answer and the question is there, where there is a replacement hip, which doesn't quite perform how it should and now I'm very much excited about the whole prospect.

Also when we talk about 3D printing, it's about printing objects, but before printing an object we have a digital object, we have a digital file. What we know from the past, the digital objects such as digital books, digital music, they're prone to intellectual property

infringement. So there is good news with 3D printing because it is about physical objects. They are protected by quite a few intellectual property mechanisms. They are protected by patents, copyright, design right and trademark. The not such good news for businesses is that all these mechanisms are rather inefficient when it comes to private usage.

So if you decide to print something at home for your own private usage, this is all irrelevant, you are not infringing anything if it is for your private usage. So it does create some potential problems and some food for thought. Also what we see today with 3D printing that people are becoming creative and again, when it comes to intellectual property, at some points not quite clear whether it is just creativity or infringement, so this is something which was not quite authorized by the property right holder, but we also have cases when users and customers are allowed to unleash their creativity. So they can customize objects, they can change colours, they can change shapes.

Again, what kind of effect it's going to have on intellectual property ownership? Who is going to be the owner of intellectual property if it is co-created by sometimes dozens of users? Well, again, luckily we can learn from the past and from the experience of, with digital roots, so one of the lessons that we can learn that when something becomes digital, piracy always takes place. We also know from the past that neither technology nor law alone can prevent piracy and finally we know that piracy cannot be prevented, but it can be avoided.

How can it be avoided? With the right business model. I'll come back to business models in a few minutes. So here we have this issue of intellectual property and companies or individual users as well being worried about their designs and their creations being infringed, but this is not the only worry they have. The other worry is about change of manufacturing process. The traditional manufacturing process as we know it, there is a design, the design is sent to a factory, it's manufactured and it's then sent to the final user. What we can have with 3D printing and other forms of digital manufacturing is that there is a design and this design is sent directly to the user, it's the user who will manufacture or produce it and even distribute it.

Or we can have users who will also participate in end design, who will provide the design. So the role of the companies is shrinking and we can even go further and say that the design itself, not be provided by the company but could be outsourced and then the role of the company will be even smaller which poses another question, what role for companies and again, it is happening. It's happening now, as the time for some businesses to start with thinking their business models. This is exactly what we do in our research centre and I'd love to give you a couple of examples, but unfortunately we don't have time.

Being the last speaker today now, I feel like I have to finish on a positive note. So it's true that there are some issues. There is some light out there and there's great potential and I think this is what makes it an amazing technology. First of all there is a lot of potential when it comes to creativity. It is very, very expensive to be creative, for businesses or individuals. If they want to be creative, they need to conduct market research which is expensive, then it's about producing prototypes which can be expensive as well. What we have with 3D printing, we have the opportunity, first of all, to lower some of the costs,

prototyping can become much cheaper. We can also speak about life objects, so objects being amended on a regular basis with the help of constant feedback from the customers.

It's much easier to make amendment to one item rather than to thousands of items and it's not any more about trying to guess what customers more, it's more about them telling businesses what they want. There's also an effect on entrepreneurship. There is some really amazing stories of how entrepreneurs tap into niche markets with the help of 3D printing. The traditional process, entrepreneurial process involves, obviously, having a great idea and convincing investors that it is a great idea and then trying to produce and sell as many items to make enough money to pay off the debt. So that's kind of the traditional process.

With 3D printing, what becomes possible is positive cash flow. So instead of going out and asking for money or using kick starter, it's about putting ideas online and waiting, it sounds very optimistic, but yes, waiting for customers to pay for the item and then produce this item and sell it to them and if we add creativity and entrepreneurship we do get increased rate of innovation. Finally, talking about long-term effects, well it is about innovation and there are amazing stories that you heard today what could be done with different materials, what could be done with different 3D printing technologies.

It is about saving costs of tooling, of transfers, of storage, of waste. It is about return of manufacturing to developed countries. It is about regional and global development, so we don't all have to live in London, we can enjoy scenic locations and have our businesses there, increased competitors and sustainable growth.