City
Cooking
Creativity
Culture
Decoding
Design
Environment

Food product
Food safety
Health
Intelligent labels
Method
Packaging

Process
Products
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Proteins
Refuse
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Society
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Urban agriculture
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Waste of resources

Bioprinting
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Technology

Davide Sher Xavier Tutó

"A company called Modern Meadow applies the latest advances in tissue engineering to the development of novel biomaterials to address some of these pressing global challenges"

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Xavier Tutó is a multidisciplinary designer, in 2004 Tutó co-founded KXdesigners Studio with Katia R. Glossmann. In 2009, together with Jordi Bayer, he created Growthobjects, a group that develops design and engineering solutions through additive manufacturing.

Review of 3D Food Printing

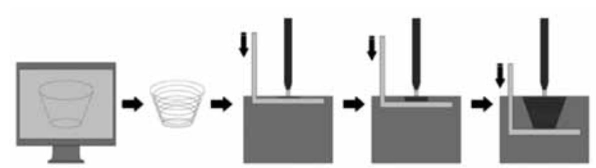
This article will discuss how the sci-fi vision of the *Star Trek* series, in which a food replicator aboard a Federation spaceship materialises elements such as tomato soup, tea or coffee (as well as alien foods) out of thin air, as if by magic, may become a real machine in the not too distant future. On the one hand, the 3D printing industrial revolution, which is currently changing how new products are designed, developed, produced, marketed and consumed, has also reached the world of cooking.

Introduction

While the crew on board the science-fictional spaceship Enterprise had access to a replicator, a machine capable of assembling atoms of matter to create any object that could possibly exist in the universe, for some unknown reason they used it primarily to prepare hot tea or other alien beverages. From its initial conception in *Star Trek* it was thus obvious that if humanity had access to a machine that could create anything, it would chiefly be used to make food. Since 3D printers can be considered the descendants of the *Star Trek* replicator, it seems simply and 'Vulcanly' logical that 3D food printers are a hot topic.

3D printers are robotic machines that create objects through a process also known as additive manufacturing. This means that instead of defining an object's shape by removing excess raw materials, they only take the necessary matter in the form of liquid, powder or filament, which the machine then melts or solidifies to create the object's final shape. This process holds great promise for manufacturing as it drastically alters all supply chain dynamics, removing the need for economies of scale and potentially reducing time, cost, energy consumption and transportation requirements. With 3D printing, even highly complex objects are assembled by a machine following the instructions contained in a digital 3D model, designed using CAD software. Much like a replicator, 3D printers shape matter in order to make objects.

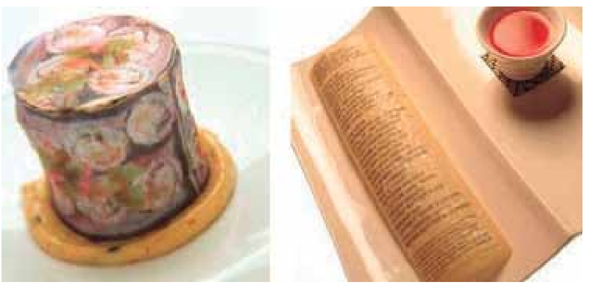
There are many different technologies and variants to 3D printing. Among the first to be invented were stereo-lithography, where objects are created thanks to the solidification of photoactive liquid resin, and binder jetting, where powdered materials are glued together layer by layer. Today, the most common and affordable process is called fused deposition modelling (FDM) or fused filament fab-



▲ Schematic diagram of additive layer manufacturing. Growthobjects.

rication (FFF), in which a spool of thermoplastic polymeric material is heated and extruded through a nozzle, in order to 'draw' the 3D layers that form the object. An alternative process derived from FDM uses a syringe to extrude paste-like materials, which do not need to be heated and are dense enough to form layers and 3D structures once deposited. Both this FDM variant and binder jetting technologies have already been used for 3D printing with food.

As in all other fields, before food was ever 3D printed, it was 2D printed. In 2005 Homaru Cantu, a chef at Chicago's Moto Restaurant,[1] made the headlines by being the first to use regular ink-jet 2D printing to design images on sushi rolls wrapped in edible paper made of soybeans and cornflour. He used organic, food-based inks of his own concoction to draw the colourful images and photos, while the technique he adopted was similar to other multi-material and multicolour 2D printing processes, also defined as ink-jet processes.



▲ Sushi roll and edible menu made with a 2D ink-jet printer. Chef Homaro Cantu, Moto Restaurant

The next step towards the third dimension (that of height, or Z-axis) was taken by Windell Oskay and Lenore Edman at Evil Mad Scientist Laboratories with their CandyFab Project. In 2007 they introduced the CandyFab 4000, an early DIY 3D printer based on a modified version of another 3D printing process commonly used today at industrial levels known as laser—or heat—sintering. In laser sintering, the powdered materials (polymers or even metals) are bound together after being partially melted by a laser beam, while heat sintering uses either infrared radiation or a heated surface. The CandyFab version of laser sintering, which would be followed by the 5000 and 6000 version in 2008 and 2009, was referred to as SHASAM, an acronym that stands for selective hot air sintering and melting. It used a focused heat source moving over a bed of sugar, fusing its particles together to create large 3D sugar sculptures.

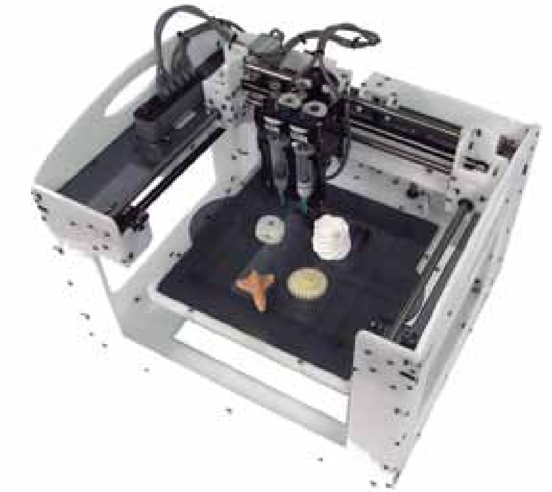
Some of the most forward-looking projects, considered advanced even to this day, were those introduced when Marcelo Coelho and Jamie Zigelbaum presented the prototypes and concept designs for the Cornucopia Project, a complete digital gastronomy solution, in 2010. The project included a family of four food printer prototypes: the Digital Chocolatier, the Digital Fabricator, the Robotic Chef and the Virtuoso Mixer,[2] which ranged from a machine capable of assembling different ingredients to make chocolate-based sweets, to an actual multi-food 3D printer (the Digital Fabricator), and a multi-arm robotic system designed to transform foodstuffs physically and chemically thanks to a range of tools.

▲ Manufacturing process with an experimental machine where the raw material is sugar. CandyFab 4000 by Evil Mad Scientist Laboratories.

The very first developments in industrial 3D printing technologies, binder jetting and stereolithography took place at the Massachusetts Institute of Technology (MIT) and at 3D Systems, which in 1987 became the very first company to produce a commercially available 3D printer. During the nineties, MIT developed a procedure it patented and trademarked with the name 3D Printing, later officially abbreviated to 3DP. In February 2011 MIT began to grant licenses to six companies to use and promote the 3DP process in their products. The best known among them is Zcorporation or Zcorp, which was acquired by its competitor 3D Systems in 2011.[3] Its 3DP technology, now also known as jet printing or colour jet printing (CJP), is still among the most commonly used today for non-functional full-colour objects.

Many new advances in 3D printing technology are still produced at universities before becoming commercial projects or companies. Food 3D printing is no different, for it is a highly relevant sector that welcomes studies from both academic and corporative communities.

In 2007 Hod Lipson and Evan Malone at the Cornell University Computational Synthesis Laboratory adapted the Fab@Home[4] open-source extrusion printer to work with food. For this project they partnered with the French Culinary Institute in Manhattan to print personalised chocolate and cheese, biscuits, cubes of puréed turkey and celery paste, and even tiny spaceships made of deep-fried scallops. For the scallops the team went so far as to blend the seafood and add transglutaminase (often called meat glue) so that the mixture would solidify again after having been extruded. For the celery, they added agar and created a celery gel. The food-printing craze is catching on in other research settings as well, and chocolate has been one of the main areas for experimentation.



▲ Fab@Home Model 2 3D printer and printed parts. Hod Lipson

Three years later, in 2010, scientists at the University of Exeter built their own 3D printer with a heated extruder for printing gourmet chocolate. They developed a new fabrication method known as chocolate additive layer manufacture (ChocALM).[5] Led by Dr Liang Hao, the study explored

1 David Bernstein, When the Sous-Chef Is an Inkjet [online], *The New York Times*, New York. 2005. [Accessed: 8 January 2015] Available at: http://www.nytimes.com/2005/02/03/technology/circuits/03chef.html

2 Hod Lipson, Melba Kurman, 'Digital Cuisine,' in Fabricated. *The New World of 3D Printing*, Wiley, Indianapolis, 2013, pp. 129-133.

3 Stephanie Crawford, 'How 3-D Printing Works' [online], *HowStuffWorks.com*, 2011 [Accessed: 8 January 2015]. Available at: http://computer.howstuffworks.com/3-d-printing.htm

4 Lauren K. Wolf, 'Personal Manufacturing' [online]. *Chemical & Engineering News*, American Chemical Society, 2011. [Accessed: 8 January 2015] Available at: http://cen.acs.org/articles/89/i46/Personal-Manufacturing.html

5 Liang Hao, Stephen Mellor, O. Seaman, J. Henderson, Neil Sewell and M. Sloan, 'Material characterisation and process development for chocolate additive layer manufacturing,' *Virtual and Physical Prototyping*, 1745-2767, volume 5, issue 2 (2010), pp. 57-64. http://www.tandfonline.com/doi/abs/10.1080/17452751003753212#.VK0nICuG98E

▲ Edible Growth project. Chloé Rutzerfeld.

the material properties and behaviour of commercial chocolate. Deposition experiments were carried out using the newly developed ChocALM system to illustrate the effects of the deposition parameters on the geometrical accuracy and dimension of the deposited chocolates. The results revealed that process parameters such as extrusion rate, nozzle velocity and nozzle height are critical for the successful deposition of chocolate, and the optimisation of these parameters enables the ChocALM system to create 3D chocolates with appropriate quality. The commercial consequence of this study was the founding by Dr Hao of the ChocEdge company to manufacture and distribute the Choc Creator, the first commercial chocolate 3D printer ever to hit the market, at a price of about £3.000. After the initial success, both from commercial and media perspectives, in 2014 ChocEdge launched the 2.0 version of its 3D printer.

Dutch University TNO has been playing a major role in university-led research projects pertaining to technology and 3D printing since 2006, when the TNO Research Center began to develop various innovative food processing technologies, including a particular food printer. Their research was embraced by Barilla, one of the world's leading pasta companies, which in 2013 announced that for over two years it has been working with TNO Eindhoven on a prototype for the perfect pasta printer, to be used in restaurants and even in the home to create customised pasta shapes.[6] The various possibilities were later illustrated in the PrintEat contest, where Barilla asked designers worldwide to come up with innovative pasta design, such as a hollow moon shape or a complex flower shape that opens up during cooking.

TNO has also worked with industrial designer Chloé Rutzerfeld to develop the Edible Growth project,[7] based on a food 3D printer that has the ability to produce mini 3D printed appetisers made from nutritional ingredients like sprouts and fungi. Multiple layers containing seeds, spores and yeast are 3D printed and within five days the plants and fungi mature and the yeast ferments the solid inside into a liquid. The product's intensifying structure, scent and taste are reflected in its changing appearance; users then decide when to 'harvest' and enjoy the fresh and nutrient-rich edible products depending on the preferred flavour intensity.

Food Printing

We do not as yet have a clear definition of what a food 3D printer is—whether it is simply a cooking machine with augmented capabilities, a tool for devising new food combinations or even something

6 Melanie Ehrenkranz, '3D Printing Food May Come To Restaurants Soon If Pasta Leader Barilla Has Its Way' [online], iDigitalTimes.com [Accessed: 8 January 2015]. Available at: http://www.idigitaltimes.com/3d-printing-food-may-come-restaurants-soon-if-pasta-leader-barilla-has-its-way-368075

7 Alec. «The Edible Growth Project: a study into sustainable, healthy 3D printed food» [en línia]. *3ders.org*, 2014. [Consulta: 8 gener 2015]. Disponible a: http://www.3ders.org/articles/20141006-the-edible-growth-project-a-study-into-sustainable-healthy-3d-printed-food.html

that one day will be able to create foodstuffs that do not yet exist. Broadly speaking, a food printer is a machine that can turn digital recipes into edible and possibly delicious morsels. The vast majority of 3D food printers currently available implement the FDM variant with a syringe-based paste extrusion system, which works a bit like an oversimplified inkjet printer with a single, large nozzle that releases dense paste material instead of many tiny nozzles releasing picoliter droplets of liquid ink. The paste material can be stacked layer upon layer to form the 3D dimensional food structures. Much like the case of 3D ceramic printers, the food has to be 'sintered' or 'cooked' in a separate post-process which may or may not take place within the 3D printer itself.

Inspired by the University of Exeter's experiments with chocolate 3D printing, in 2012 Richard Horne presented his Universal Paste Extruder at the popular Richrap.com website. His goal was to enable any open-source 3D printer to experiment with a number of different pastes, including food and ceramic materials. The UPE is driven by gears and uses a driven belt to press down on the standard 10 ml syringe, thus keeping the height to a minimum in order to allow maximum build height.

Structur3d 3D printing, a company based in Ontario, has made its own Discov3ry 3D printing paste extruder available for pre-order, promising it can be used to 3D print with any paste material—from Nutella chocolate paste to silicon and wood filler. The system has been designed to work with almost any FDM based 3D printer, replacing the molten plastic extruder. It works by forcing material out of reusable, affordable and easily available syringes, through a feed tube, and finally an extruder tip mounted to the printer head carriage.

Another paste extruder, the Plastruder, dates back several years. In its many different versions, it was implemented and offered by MakerBot in 2010 as the MK5 version, which featured an all stainless-steel hot end which was precision machined to fit tightly together and prevent leaks. The UNFOLD version of the Plastruder was used in 2012 by designer Ralf Holleis to 3D print Christmas biscuits based on original CAD designs. They were extruded on to wax paper and then easily transported to the oven for 'post-production'.

Following up on these DIY solutions, some newer 3D printers such as the Zmorph, FABtotum and byFlow, have introduced easily interchangeable print heads which enable the same 3D printer to be rapidly adapted to the use of thermoplastics such as ABS, PLA or nylon and to paste materials such as chocolate and other edible products. The manufacturers of these 3D printers generally make the technical data pertaining to their machine available to all, so that the community of users can develop and use alternative extruders that fit their own specific needs, including that of using the machine to create edible products. Other commercial projects focus primarily on the food printing aspect. These include the previously mentioned Choc Creator by Choc Edge[8] and the Imagine 3D Printer by Essential Dynamics, which has been built to use paste based materials such as silicone, epoxies, organics, cheese and chocolate.

▼ 3D Printed Christmas Cookies. Ralf Holleis - Unfold.

8 '3D Printer that Prints in Chocolate Now Available!' [online], 3Dprintplan.com, 2012 [Accessed: 8 January 2015]. Available at: http://www.3dprintplan.com/2012/01/26/3d-printer-that-prints-in-chocolate-now-available/

While it is by far the most common, extrusion-based fabrication is not the only process used to3D print with food. Along with sintering and binder jetting experiments, Laser Cooking[9] is novel cooking technology that uses a laser cutter as a dry-heating device. In general, dry-heat cooking heats the whole surface of an ingredient, while a laser cutter heats a small spot of the surface in a very short time.

Alternatively, another 'subtractive' digital fabrication technology such as CNC milling has been implemented in the Icepop Generator, a concept machine created by Melt Icepop, based in the Netherlands. Placed in a freezer, it works as a mechanical ice sculptor, using a drill that travels back and forth across three axes. The design is thus carved out of a block of ice, with a fourth axis used to rotate the ice in order to create more complex figures.

The US Army in particular is very interested in the possible applications of food 3D printing on the battlefield. As the army website reveals, as head of a research team within the Combat Feeding Directorate (CFD,) food technologist Lauren Oleksyk is investigating 3D printing applications for food processing and development. One possible application is ultrasonic agglomeration, which binds particles together by shooting ultrasonic waves at them. This approach affords great flexibility when it comes to printing a wider variety of meals, adding several supplementary options to a soldier's menu.

Edible Materials

In 2013 designer Janne Kyttanen, one of the very first visionaries of consumer 3D printing applications over a decade ago, produced plastic prototypes of 3D printed pasta, cereal and even hamburgers to prove the point that 3D printing technologies are capable of transforming the way we eat. Kyttanen is convinced that once we are able to easily assemble the elements that compose our foods we shall use

▲ Food is the next frontier of 3D printing. Janne Kyttanen

the capabilities of 3D printers to make food into the most amazing and customised shapes imaginable. He goes so far as to predict that the future of food 3D printing really is the *Star Trek* replicator, where a machine will assemble molecules in combinations that can yield tasty and nutritional meals.

Even before moving on to molecules, though, pasta has been offering researchers plenty of possibilities with which to experiment. This includes Barilla's previously mentioned PrintEat contest and TNO's pasta 3D printer, as well as a further development of the Fab@home project developed at Cornell University. In this new iteration, Hod Lipton's team used the 3D printer to assemble ramen noodles in a variety of artistic shapes.[10]

Perhaps the most common use for pasta, albeit a different type of pasta known as dough, is for pizza. Pizza itself is an additively made product: the first layer being the pasta, the second being the tomato sauce, third the mozzarella cheese, then toppings and so on. Built by four mechanical engineering students at the Imperial College of London, the F3D printer is capable of manufacturing and cooking a regular Margherita pizza in just about twenty minutes. Using three different syringes it extrudes dough flour, tomato purée and cream cheese.

The US Space Administration NASA knows that 3D printing is the key to long term space missions as it would allow astronauts to carry along just the raw

9 Kentaro Fukuchi, Jo Kazuhiro, Akifumi Tomiyama, Shunsuke Takao, 'Laser Cooking: A novel culinary technique for dry heating using a laser cutter and vision technology,' in CEA'12. Proceedings of the ACM Multimedia 2012 Workshop on Multimedia for Cooking and Eating Activities, ACM, New York, 2012, pp. 55-58.

10 A. J. Jacobs, 'Dinner is Printed' [online], The New York Times, New York, 2013. [Accessed: 8 January 2015]. Available at: http://www.nytimes.com/2013/09/22/opinion/sunday/dinner-is-printed.html?pagewanted=all

materials and the CAD designs for every replacement part they could possibly need (instead of carrying every single one of the actual parts that might break). For this reason a 3D printer was recently delivered to the International Space Station and in future it may be used to prepare astronaut meals as well as tools. NASA awarded the Systems and Materials Research Consultancy of Austin, Texas, a $125.000 contract to develop a 3D printed food system for long-duration space missions. NASA's Advanced Food Technology programme is interested in developing methods that will provide food to meet safety, acceptability, variety, and nutritional stability requirements for long exploration missions, while using the least amount of spacecraft resources and crew time.[11]

Chocolate and sweets still remain at once the ultimate and closest objective of food 3D printing. While chocolate can be extruded through a heated syringe system, new technology implementations are already looking at laser as a way to melt 3D printed chocolate powder and form three-dimensional geometries, as was done by four mechatronic engineering students at the University of Waterloo, 3D Chocolateering. Much like the previously mentioned CandyFab project, their machine consists of a sintering system that uses laser to selectively melt powdered chocolate. Since laser sintering does not require the presence of supporting structures, this allowed for the creation of highly complex geometrical figures. For the students it was also an exercise in creating a low-cost sintering system, given that current laser sintering machines cost over €200.000.

While creating the 3D printed sweets is a big part of the process, much like in industrial and consumer 3D printing, the finish is just as important as the proverbial icing on the cake. The Vienna-based design studio mischer'traxler presented a digital, automatic cake decorator at the Vienna Design Week in 2014. Titled Till You Stop, the project's underlying goal is the exploration of a new kind of personalised food manufacturing, where the consumer's decision to say 'stop' defines the outcome of the design.

Digital Gastronomy (Food Printers)

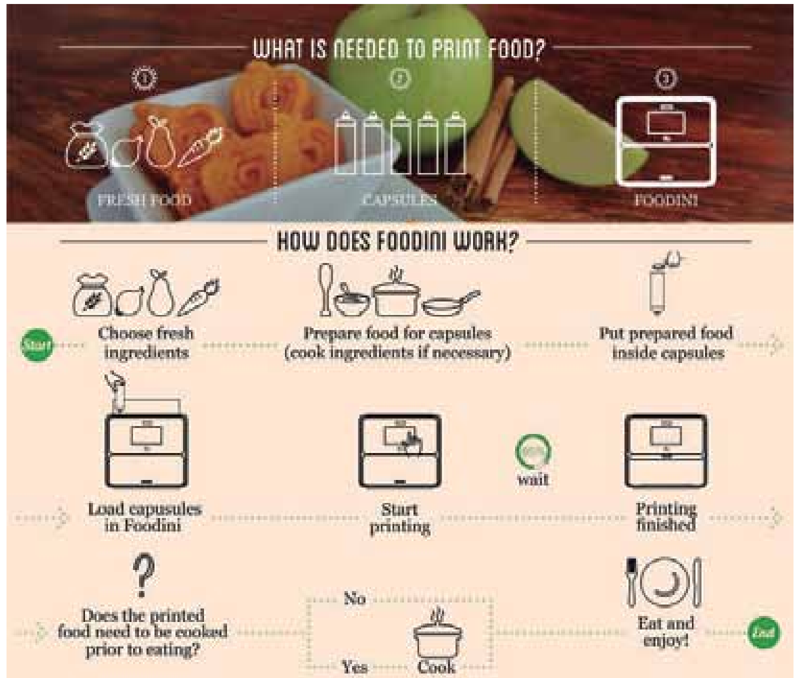
While all the previously mentioned projects are ambitious and hold an incredible long term potential, 2015 is likely to be remembered as the year when the very first truly commercially available food 3D printers will hit the market. Three different systems will contend for the sceptre of most kitchen-ready food 3D printers: two of them are manufactured by 3D Systems and have sugar and chocolate as the main printing materials; the third is the Foodini, an equally ambitious multi-food 3D printer designed and built by a Barcelona based start-up company called Natural Machines. Others are already following in their footsteps.

Announced early in 2014, the Chefjet originates from a project carried out by The Sugar Lab design studio based in Los Angeles. The two-person studio developed a machine that implemented a technology very similar to Zcorp's, except that it used water instead of glue as a binder for the sugary powder. The patents owner, 3D Systems, found it more convenient to purchase the studio rather than to sue them, and the Chefjet was the result of this alliance. It is meant to be the first in an entirely new, kitchen-ready category of 3D printers for food. The first two printers in the series are the monochrome, countertop ChefJet 3D printer and the full-colour, larger format ChefJet Pro 3D printer. Destined to the professional baker, pastry chef, mixologist and restaurateur, these printers allow the creation of custom edible geometries and will be made available with ChefJet printable materials for a variety of recipes, including sugar, different flavoured sweets and milk chocolate.

Focusing specifically on chocolate manufacturing, the Cocojet is the result of 3D Systems' partner-

11 '3D Printing: Food in Space' [online], NASA.gov, 2013. [Accessed: 8 January 2015]. Available at: http://www.nasa.gov/directorates/spacetech/home/feature_3d_food.html#.VK55fiuG98E

▲ Food Form 3D by Robots in Gastronomy. Robots in Gastronomy.



▲ 3D Printer Foodini: how it works. Natural Machines.

▲ Veggie burger printing with Foodini. Natural Machines.

▲ Foodini by Natural Machines. Natural Machines.

ship with Hershey, a global leader in chocolate and confectionery. This is a standard machine based on 3D Systems' own version of FDM technology, which the company refers to as Plastic Jet Printing (PJP). In fact, the Cocojet is a modified version of 3D Systems' Cube Pro 3D printer for plastic filament.

The Foodini 3D printer is perhaps the most revolutionary and promising of all the commercial 3D printers. It uses a syringe-based system to extrude a series different paste materials (anything from dough to chopped meat) and the reason why it is so revolutionary is the company's approach. The underlying idea is that, by mixing healthy base ingredients, the Foodini will be able to robotically prepare healthy home-cooked meals for those whose lives are so full that they have no time left for cooking anything. Developed in collaboration with Elisava Barcelona School of Design and Engineering, the Natural Machines device can use six capsules of different materials, allowing much more complicated foodstuffs to be made. It also has a built-in heater to keep the food warm during the printing process. The current projected retail price will be around $1,000.

Robots in Gastronomy (RIB), also based in Barcelona, is a global hub for culinary experimentation. Its research and design group focuses on the intersection of technology and gastronomy. Led by Luis Fraguada, the team includes Michelin star chefs, industrial designers, interaction designers and high-end kitchen equipment distributors. The group's research has culminated in the creation of the Food Form 3D, a computer numerically controlled deposition robot capable of 3D printing edible materials. The aim of the group is not to industrialise the kitchen as much as to provide tools of invention and innovation.

Together with 3D Systems, one company that is very keen on conquering the consumer public with its 3D printers is XYZ Printing. The firm's newest sub-$2,000 printer, introduced at the Consumer Electronics Show in Las Vegas in January 2015, is expected to come on the market in the second half of the year. It is capable of 3D printing dough-based foods that, once cooked, can turn into pastries, cakes and more.

▲ Full-colour 3d printed sugar confection made with ChefJet pro. 3D Systems.

"Developed in collaboration with ELISAVA, the Natural Machines device can use six capsules of different materials, allowing much more complicated foodstuffs to be made"

Molecular Gastronomy

On the subject of fusing technology and cooking, especially in Catalonia, one cannot but mention molecular gastronomy techniques. Some of the elements that characterise molecular gastronomy processes, such as the use of sodium alginate to induce the jellification and solidification of liquids, can be used in extrusion-based digital fabrication processes and even have applications in the field of bio-printing (3D printing of human tissues). The evolving combination of molecular gastronomy technologies and processes is likely to drive us closer to the *Star Trek* replicator.

Based in Cambridge, Dovetailed got ahead by developing a 3D fruit printer by combining a digital print head and the spherification process of molecular gastronomy. It uses sodium alginate to create caviar-like gelatinous ‘bubbles’ with a liquid interior from fruit juice. The first experiment carried out by Dovetailed consisted in using strawberry-flavoured juice to create a series of caviar-like bubbles, which were then assembled to form a strawberry-flavoured 3D printed fruit that looked just like a raspberry.

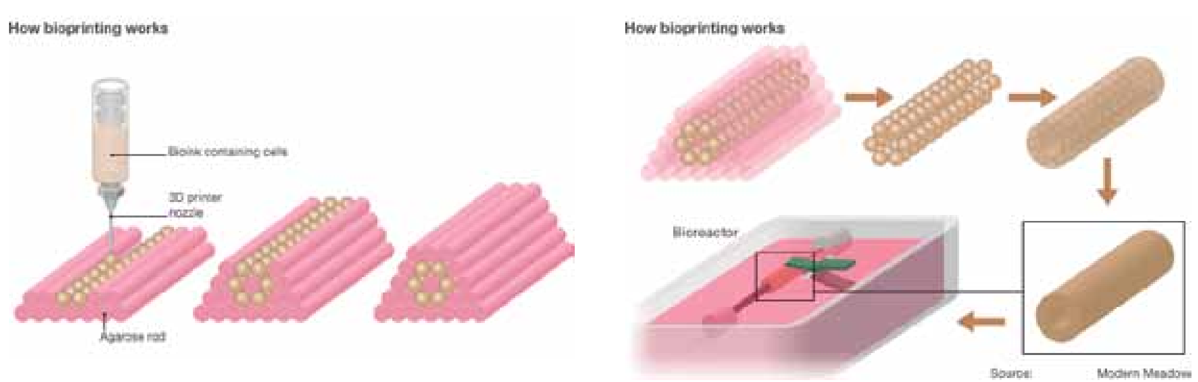
As curious as the Dovetailed process may be (the flavour is still not quite entirely satisfactory, but that may be an issue pertaining to molecular gastronomy rather than to 3D printing), the final frontier in molecular food assembly is meat manufacturing. Intensive animal farming is not only increasingly perceived as an extremely cruel practice but is also a major cause of global warming and depletion of the world’s hydric resources. A company called Modern Meadow[12] applies the latest advances in tissue engineering to the development of novel biomaterials to address some of these pressing global challenges. It has thus developed cultured leather and meat products which require no animal slaughter and much lower inputs of land, water, energy and chemicals.

▲ 3D fruit printer. Dovetailed

Set up by father-son team Gabor and Andras Forgacs, this start-up company is making artificial raw meat using a 3D bio-printer. In order to bio-engineer meat, scientists first harvest stem cells, i.e. cells capable of turning into any type of the animal’s cells, through the common procedure of the biopsy. As scientists feed and nurture them, these cells are also able to replicate themselves many times and grow into strands. They are then inserted into a bio-cartridge to be 3D-printed into the desired shape to form living tissue, which has the exact same biological composition of meat from a live cow. Roughly 20,000 of these strands are required to make the normal sized hamburger created by Dutch scientist Mark Post from the University of Maastricht to show that meat grown in a Petri dish might one day become a true alternative to meat from livestock.

Another group working along the same lines is Future Food, an Internet initiative based in Austria

▼ Modern Meadow. How bio-printing works. Left: Bio-ink containing various types of cell is printed into moulds made from agarose gel. Right: After several days the bio-ink fuses and the agarose support is removed. The tissue is put into a bioreactor and given low frequency stimulation to mature the muscle fibres.



that seeks to build a global awareness regarding real alternatives to animal derived products. They explain that these products can be divided into two groups. The first is described as including vegetarian meat, non-dairy milk drinks and egg replacements, all of which are products that simulate or copy animal derived products.

The second is in-vitro meat or cultured meat, foodstuffs that are made of actual meat produced without the use of animals. While the possibility of a synthesised in-vitro grown burger may not be tempting to many, much of its real appeal to consumers will be determined by the appearance of the artificial meat. Future 3D printers will be able to assemble easily digestible foods, not only maintaining the shape and taste of the real thing, but also able to be strengthened with specific nutrients and shaped to be visually appealing. In nursing homes it is estimated that up to 60% of patients suffer from a condition called dysphagia, which makes it difficult and even dangerous for them to swallow their food. As a result they are often fed porridge-like food that has been puréed and blended from a variety of ingredients. Scientists at Biozoon Food Innovations in Germany participating in the PERFORMANCE project funded by the European Union are working on reconstructing food servings into a more digestible form that is also appetising to the eye, such as a chicken fillet that may be cooked, puréed and strained and its liquid then used to produce a jellified portion of chicken that can be safely digested. The three-year PERFORMANCE[13] project hopes to develop food 3D printer technology and specialised texturing systems to produce safe and appetising meals.

The 3D printer will work in the same way as an ink-jet printer, using capsules filled with liquefied food: one for vegetables, one for meat and one for carbohydrates. It will create the first layer of the

▲ A burger made from Cultured Beef. David Parry / PA Wire

food, for example, the two-dimensional form of a chicken wing, with liquid from the meat cartridge, shaped by the 48 nozzles in the printer head. A jellification agent, currently under development, will be added to the liquid in the cartridges. Layer after layer, the desired shape will be applied to the food, which may be that of a chicken wing and yet have any desired flavour.

> “In order to bio-engineer meat, scientists first harvest stem cells, i.e. cells capable of turning into any type of the animals cells, through the common procedure of the biopsy”

12 Francoise Marga, Modern Meadow, ‘Engineered Comestible Meat’ [online], United States Department of Agriculture, 2012. [Accessed: 8 January 2015]. Available at: http://www.reeis.usda.gov/web/crisprojectpages/0228895-engineered-comestible-meat.html

13 Damien Pearse, ‘*Transforming* Mealtimes with 3D-Printed Food’ [online], *Horizon. The EU Research & Innovation Magazine*, 2014. [Accessed: 8 January 2015] Available at: http://horizon-magazine.eu/article/transforming-mealtimes-3d-printed-food_en.html

Conclusions

The aim of Future Food organisation, shared by other similar initiatives, is to bring animal suffering, environmental pollution, starvation and health risks to an end by ceasing to use billions of domestic animals as meat, milk and egg machines, replacing these products with other healthier products obtained thanks to more environmentally-friendly and ethical means.

Traditional production of meat, milk and eggs from animals puts far more strain on the environment than any other kind of food production. As a result of the increasing world population and the steadily decreasing amount of agricultural land, mankind needs to find viable solutions to satisfy its alimentary demands. Around 55 billion chickens, turkeys, pigs, cows, sheep and ducks are killed and slaughtered yearly throughout the world. There is a discrepancy between science and awareness of animal welfare in society on one hand, and the practice of industrialised livestock farming on the other.

Eating animals means that the food chain—starting with plants and ending with human beings—is extended, as a result of which a lot of food that could be used to feed people is wasted. Paradoxically, the over-consumption of meat is increasingly regarded as one of the major causes of many typical complaints, including cancer and heart disease.

The Food and Agriculture Organization of the United Nations (FAO) estimates that the demand for meat will increase by over two-thirds in the next forty years and that current production methods will cease to be sustainable. In the near future, meat and other staple foods are likely to become expensive luxury items thanks to the increased demand on crops for meat production. That is, unless we find a sustainable alternative.

Livestock contributes to global warming through unchecked releases of methane, a greenhouse gas twenty times more potent than carbon dioxide. The increase in demand will significantly increase levels of methane, carbon dioxide and nitrous oxide and cause a loss of biodiversity.

Along with appearance, taste is likely to be an important key for the success of future foods and, at the same time, one of the biggest challenges. Will we stomach it? Our eyes are typically bigger than our bellies and, as we have seen, printed meat could be manufactured in familiar shapes and textures, so therefore our palate will be a dominant factor.

Future Food believes that artificial or 'bioficial' food products will necessarily be cheaper than conventional meat, milk and eggs derived from animals. They will also be potentially healthier than animal products, with a number of additional benefits directly related to the possibility of tailoring meals.

Restaurants might be able to tap information about their diners' medical history, dining habits and exercise regimens, then whip up meals to precisely suit their health needs, even before they're ordered. 'In five years 3D printed food will be served in nursing homes,' says researcher Kjeld van Bommel of TNO. TNO is also working on a 3D printer that makes puréed food attractive for patients with chewing and swallowing problems. 'These people can now get real food on their plate. With a knife and fork they feel enabled. They could eat better and enjoy an improvement in their quality of life,' says van Bommel. 'It should also be possible that the 3D printers customize meals to meet their specific needs, for example by integrating calcium for patients who suffer from bone deficiencies.'

As has been the case in every application of 3D printing, one of its greatest promises is the customisation of production. In the food sector, this entails the virtually new concept of truly personalised nutrition. The elderly, the youngest and those who suffer from disabilities and health deficiencies will be the first to benefit from tailor-made foods, and in a second phase these benefits may be extended to humanity as a whole. This will, of course, entail a carefully balance of the requirements for a more healthy and sustainable way of life with the human need for a more traditional culinary culture, which coincides with TNO's vision of future 3D-printed meals made up of alternative food ingredients including algae, duckweed, grass, lupine seeds, sugar-beet leaves and insects.

While there is little doubt that it will produce benefits for the world as a whole, it remains debatable whether 3D-printed food can actually be integrated in the global supply chain. The question is whether 3D-printed meat can actually become an economically viable solution and whether consumers will accept it.

The public will want to know whether printed foods are safe for human consumption. As is often the case, many practices that seem remote or even alien to current generations may turn out to be quite natural for future generations, particularly if their benefits are proven. Multinational interests and conflicts of interest may raise doubts on the benefits of such new practices in the field of food printing, however it remains undeniable that the current state of industrial animal farming is no longer sustainable.

Consumers will quite likely demand appropriate protection to ensure that the development of printed food neither limits their access to organic produce nor contaminates it. It is reasonable to assume that most of them will want to decide whether they eat 'real' meat or try printed meats, therefore labelling regulations will be important.

To further understand the possibilities that lie ahead, Next Nature published the *In Vitro Meat Cookbook*.[14] Using the cookbook format as a storytelling medium, the publication visually explores the new food cultures that laboratory-grown meat might create, approaching the subject from the points of view of design and engineering, but also from societal and ethical perspectives, and suggests we think of revived dodo wings, meat paint or meat ice cream, cannibal snacks, steaks knitted like scarves and see-through sushi grown under perfectly controlled conditions, for example.

The race is on, especially if you see the announcement that could materialise the Nestlé Iron Man project, with which the food giant intends to develop its own version of the replicator within five to ten years. Described as 'the next microwave', the machine in development at the Nestlé Institute of Health Sciences is a system that can test people's health requirements and work out the nutrients that are missing from their diets; eventually it will lead to a machine capable of producing tailored supplements or even food. If in doubt, just keep an eye on the near future.

14 Koert Van Mensvoort, Hendrik-Jan Grievink, *The In Vitro Meat Cookbook*, Next Nature Network / BIS Publishers, 2014.