Strategy in 3D printing of food PICMET 2018

Strategy in 3D Printing of Food

Harm-Jan Steenhuis[1], Xin Fang[1] and Tolga Ulusemre
Dept. of Business, College of Business, Hawaii Pacific University, Honolulu, USA

***Abstract*—Additive manufacturing was developed in the 1980s and for a long time, it had limited applications. In recent years additive manufacturing has found increasing uses in a variety of industries such as the medical field and the construction industry. One industry in particular that has received increasing attention is that of 3D printing food. One of the parties that is interested in this is NASA as 3D printing improves the ability for space exploration. In this study, we examine the current technological developments in the 3D food printing industry. The focus is on describing the main technologies that are applied in this industry, the materials that are being printed, and the main companies and business strategy. It is concluded that the industry is very young and that most of the commercialization is based on the application of only one of the seven additive manufacturing technologies.**

I. INTRODUCTION

Additive manufacturing, also known as 3D printing, is often compared to the concept of the *Star Trek replicator* [1, 2]. It is a production process where physical parts or structures are built by laying down successive layers of materials, i.e. adding materials. This is in contrast to the traditional subtractive process where for example a production process starts with a block of metal and then material is removed until the final product remains [3]. 3D printing has grown rapidly in recent years because of its great potential in several application forms such as rapid prototyping, on-demand production, facilitating complex design and product innovation, reducing waste, shortening design cycles as well as supply chain, and reconciling the conflicts between customization and economies of scale.

3D printing has been applied in a variety of industries such as aerospace, car manufacturing, construction, clothes, shoes, and in different forms for medical applications such as printing prosthesis and dentures [4]. Another industry that has been affected by 3D printing is the food industry. For example, with the help of 3D printing, a kitchen tool, i.e. a heated butter knife, was created [5]. Another example is the Ripple Maker, a 3D printer machine that prints images on coffee foam [6]. 3D printing has also been applied in the food production process. Food printing dates back to 2005 when an ink-jet two-dimensional was used to design images on sushi rolls [7]. NASA is an example of an organization with a high interest in 3D printing of food as it makes space exploration more feasible [8]. The preparation of food has already been the topic of automation, for example robotics-based technologies are developing to automate the cooking process and to improve efficiency in mass food production [9]. Compared to this, an advantage of 3D printing is that it is customized, therefore, 3D printing technologies could be used to obtain nutritionally personalized 3D food [10, 11].

From a technology perspective, it is worthwhile to examine the 3D food printing industry. How a technology originates and how it is diffused or commercialized are important topics in the management of technology [12]. Literature exists that deals with the management of the innovation process [13, 14] and with explaining the process of innovation diffusion [15]. Nevertheless, this topic continues to be of importance for scientific studies and frequently new studies appear that examine and explore technological development [16-18]. What makes it interesting to study the 3D printing of food is that food, of course, is very important and everybody needs it. Thus, the potential market for this technology is huge. Food 3D printing also offers an opportunity to provide customized ingredients. A healthy diet, especially at an early age, is a key factor to prevent many diseases [19] and many people suffer from diseases and conditions that requires food adjustment [10]. Most of these customized food products, are currently designed and made by specially trained artisans [20] but 3D food printing can provide an alternative. Additionally, there are complications with printing because of the material that is being printed, that is, food. Dealing with food means that there are safety concerns for the 3D printing process. Lastly, one of the main challenges for 3D printing of foods is the challenge to print self-supporting structures and to maintain the 3D shape [21].

With the above in mind, the purpose of this study is to explore the 3D printing of food. Three research questions were posed:

- What additive manufacturing technologies are currently applied for the 3D printing of food?
- What materials are being used to 3D print food?
- What companies are active in the process of 3D printing food and how do they compete?

The paper is organized as follows. In the next section, the literature related to additive manufacturing technologies will be reviewed. After this the methodology is described followed by the findings of the study. Last, conclusions are drawn.

II. ADDITIVE MANUFACTURING TECHNOLOGY

In January 2012, the ASTM International Committee F42 on Additive Manufacturing Technologies approved a list of seven AM process categories with names and definitions. These seven categories are: vat photopolymerization material extrusion, powder bed fusion, material jetting, binder jetting, sheet lamination, and directed energy deposition [22].

The Vat Photopolymerization technology can be traced to 1984. This is when Chuck Hill, who became the founder of one of the largest 3D printing companies, i.e. 3D Systems, filed for a patent, that is, US Patent 4575330. In Vat Photopolymerization, there is essentially a container with a chemical liquid. A print bed is near the top of the container so that only a small layer of the liquid is on top of it. This layer is then exposed to light, typically a laser, which then solidifies it thereby creating a first layer of material. The print bed is then lowered a tiny fraction so that another thin layer of the liquid goes on top of the material that was just formed. The process is then repeated until the product is completed.

The material extrusion technology can be traced to 1989. This is when Scott Crump, who became the founder of another large 3D printing company, i.e. Stratasys, filed for a patent, that is, US Patent 5121329. This approach is most similar to the regular 2D printer. In this situation, there is material, often a type of plastic that comes on a spool. This material is led through the extruder, i.e. the printer head, where it is heated so that it melts. It is then spread on the surface similar to the printing of letters. However, in this case, additional layers are put on top of each other, similar to printing the same letter on the same spot of paper over and over again so that the ink layer becomes thicker and a noticeable three dimensional structure appears.

The powder bed fusion technology can also be traced to 1989. This is when Carl Deckard, who was at the University of Texas at Austin, applied for a patent, that is, US Patent 4863538. Carl Deckard was a co-founder of Carl Deckard who was at the University of Texas at Austin and co-founder of another 3D printing company, i.e. Nova Automation. Nova Automation later became DTM which was acquired by 3D Systems in 2001.

Material jetting is a process in which droplets of build material are selectively deposited onto a build bed to develop a three-dimensional object. Binder jetting is somewhat similar, but with this approach a binding agent is jetted, typically into a powder, so that it binds the material. The sheet lamination technology is somewhat different. With this approach layers of adhesive-coated laminates are glued together and after that, they are cut to shape. The seventh, i.e. last category, is directed energy deposition. This is approach is, to some degree similar to material extrusion. With this approach there is also a nozzle but compared to material extrusion, the nozzle is mounted on an arm that can move in multiple dimensions. Melted material is then deposited onto the build platform where it solidifies.

III. Methodology

This exploratory study centers on an exploration of the development of 3D food printing. Of the five main research strategies, i.e. survey, experiment, case study, grounded theory approach and desk research [23], the desk research strategy was selected because this fit with the exploratory nature of this study.

Desk research is characterized by: 1) the use of *existing material*, 2) the *absence of direct contact* with the research object, and 3) looking at the material being used from *a different perspective* than at the time of its production [23]. The most important characteristic is that the material used has been produced entirely by others. Three categories of existing material can be used for carrying out a desk research project: literature, secondary data, and official statistical material. Literature is understood to mean books, articles, conference proceedings etc. Secondary data is empirical data compiled by other researchers. Official statistical material is data gathered periodically or continuously for a broader public [23].

Due to the newness of the industry and therefore the limited amount of secondary data and official statistical material, the focus in this study was on literature. In particular, articles and news from industry sources and some academic sources. The search was kept broad so that literature from a variety of sources representing a variety of perspectives which helps with forming a picture of what is happening in this industry. Literature sources included company websites, news reports, journal articles and academic reviews. Examples of academic journals that were included in the search for information were: Journal of Food Engineering, Trends in Food Science & Technology, and Innovative Food Science & Emerging Technologies. Articles in these types of journals provided insight into details of 3D food printing technologies and materials. Additional information was retrieved by searching online for information on the history and development of the companies that were identified as being active in 3D printing of food. For instance looking for information on their founding and product development. More stories were found in news reports and 3D printing industry newsletters such as: 3dprint [24], 3dprintingindustry [25], All3DP [26].

IV. Findings

A. *Technologies employed in 3D food printing*

The technologies that are applied in 3D food printing are related to the properties of the edible materials that are printed. For powders with low melting points like sugar [27], selective sintering is used which can generate multiple layers of a food matrix with each layer containing different food material components [28]. Selective hot air sintering and melting (SHASAM) use a beam of hot air to selectively fuse together sugar powder and print sugar-based 3D objects [27]. An example of this approach is CandyFab which used it to build several printers that 3D printed sugar-based products [29]. Selective sintering offers the freedom to quickly build complex food items in a short time without post curing. This technology however, is complicated as there are many variables involved [20].

Another technology applied in 3D food printing and dealing with powder is liquid binding or binder jetting [30]. This technology offers advantages such as faster fabrication and low materials cost, but suffers from rough surface finish and high machine cost [20]. 3D systems used this type of approach with their ChefJet printer [31.]

For liquids or a paste, technologies such as hot-melt extrusion [32], part of the material extrusion category, are utilized. With this technology, the material is heated slightly above its melting point so that it solidifies almost immediately after extrusion and welds to the previous layers [20]. At room temperature, soft-materials extrusion has been used in combination with materials such as dough, meat paste and processed cheese [27]. Besides the variant with a syringe-based paste extrusion system, the invention of the Universal Paste Extruder in 2012 opened the doors for printers capable of printing a number of edible paste materials, so was the invention of Plastruder, i.e. a stainless-steel hot end, and its UNFOLD version in 2012. Easily interchangeable print heads enables manufacturers to easily adapt the printers of other major 3D printer manufacturers [33]. An example of a material extrusion based printer is the PancakeBot which uses this technology to create pancakes layer by layer [34]. Food printing based on material extrusion generally feature a compact size, and low maintenance cost. But, there are also some imperfections that need further improvement, such as the seam line between layers, a long fabrication time, and delamination caused by temperature fluctuation [20].

Another approach used for 3D food printing is inkjet printing, or material jetting [35]. The drops can form a two and half dimensional digital image as decoration or surface fill. An example of this type of application is FoodJet [36].

Concerns for humane purpose, starvation, environmental pollution, and health risks helped push the development of bio-printing to produce meat products without slaughtering animals. Bio-printing is a special type of 3D technology which has been originally applied to build tissues without any biomaterial-based scaffold. This technique relies on the precise layer-by-layer deposition of biological materials and culture of living cells [27]. For example Dutch scientists have prototyped meat grown from beef stem cells but while their initial prototype convincingly looked and tasted just like a real burger, developing it cost a prohibitive $331,000 [37]. While the material properties used in bioprinting are under-going technological change, the process of 3D printing of biomaterials relates back to the previously identified categories and in particular relate to material jetting and material extrusion [27].

In some cases there are combinations of technologies. For example the use of multiple-printheads and multiple materials makes it possible to print food items or a whole meal with more recipe choices [38].

B. *Materials used in 3D food printing*

The exploration of edible materials, which have the properties of printability, can help to meet the demand for customized food items for special groups who need special blends of nutrition or textures, such as elderly, children, patients, soldiers and astronauts. The term printability is defined as the properties that allows the material to be handled with dimensional stability and that is capable of supporting its own weight [27]. In the development of printing materials for food, the capability of building complex structures and textures while incorporating nutrition values, as well as the pursuit of a cooking-resistant structures are essential [27]. Furthermore, high printability enables the fabrication of constructs with geometric complexity. This opens the possibility for the applicability of 3D printed food for artistic design with customized shapes and controlled texture [39]. Currently, raw food materials that are used in 3D food printing include: sugar [20, 27], chocolate [40, 41], cheese [42, 43], cereals [44], fruits [45], cookie dough, and ground meat [46].

The 3D printing technologies adopted in food printing combined with the (edible) materials are summarized in the Table I.

TABLE I 3D FOOD PRINTING TECHNOLOGY AND MATERIAL

Technology	Sub-category	Materials
Material extrusion	Hot	Chocolate, confection
	Room temperature	Frosting, processed cheese, dough, meat/scallop puree
	Cold	Ice-cream
Powder bed fusion	Hot Air (SHASAM)	Sugar
	Laser (SLS)	Sugar
Material jetting	Ink Jet	Chocolate, liquid dough, sugar icing, meat paste, cheese, jams, gels, fruit juice
Binder jetting	Liquid binding	Chocolate, sugar

C. *Major 3D food printer companies*

The different technologies were identified that are being used for 3D food printing in section A above. However, many of the new advances in 3D food printing technology are made at universities or scientific labs and the commercial application through companies is limited

For example Fab@home (Cornell University) was the first to adopt extrusion in food printing. They are dedicated to design teaching tools and explore new materials. Chocolate was among the first materials that they experimented with and it became one of the main application of 3D food printing [27]. Dr. Hao (University of Exeter) led a new fabrication method applied specifically to chocolate and founded the firm ChocEdge. This led to the creation of the first commercialized 3D chocolate printer around 2010-2012. ChocEdge, is currently still specialized in Chocolate printers.

Another example is the Netherlands-based TNO. This is a research organization and the only organization that deals with soft-materials extrusion, melting extrusion, liquid binding (PBP) and bioprinting. TNO collaborated the Italian food company Barilla and developed a pasta printer around 2013 [47]. TNO also developed liquid binding technology using Water soluble protein and/or a hydrocolloid [48] and also worked with industrial designer on a bioprinting project called Edible Growth [49].

For situations where a company has been formed that sells a 3D food printer, fourteen companies were identified. Included were only those companies that are beyond the concept stage and which offer the printers. For instance, 3D Systems acquired Sugar Lab in 2013 and within a year came out with the ChefJet and ChefJet Pro printers [31]. However, since then not much has happened. In August 2017 there was another announcement indicating a partnership of 3D Systems with CSM to bring the food printer to the market [50] but as of January 2018, the company website contains limited information on its involvement in the 3D printing of food. Therefore, 3D Systems and its ChefJet food printer were not included. Another example is Message in a Cake. This project was started by Daniel Wilkens when he was a student at Folkwang University of the Arts [51]. Although there is a working printer, this does not seem to be for sale commercially and therefore is not included.

TABLE II: 3D FOOD PRINTING TECHNOLOGY AND MATERIAL

Technology	Company	Year	Materials
Material extrusion	PancakeBot	2010	Pancake
	Zmorph	2013	Chocolate and cake batter
	Natural Machines	2015	Multi-material Foodini
	Beehex	2016	Pizza, cake decorations
Material extrusion (Melting capable)	ChocEdge	2010	Chocolate
	byFlow	2010	Chocolate
	Essential Dynamics	2012	Chocolate and others
	Structur3d	2013	Chocolate, frosting
	ORD solutions	2015	Chocolate, pasta
	Procusini	2015	Chocolate, icing, cream cheese, jams, mixes, batters
	Becoda	2015	Chocolate
	Shiyin Tech	2016	Chocolate, cheese, jam, candy, biscuit, multi-material
Binder jetting	Dovetailed	2014	Fruit
	FoodJet printing systems	2015	Chocolate, liquid dough, sugar icing etc.

Table II shows the 14 companies, the different technologies they have adopted, the year their printer became available, and the food items their printers are capable of printing.

Table II illustrates that in cases where 3D printing food has been commercialized, i.e. a company exists, and that most of these companies are based on material extrusion. Furthermore, many firms are specialized in chocolates/sweets food printers. For instance, byFlow, Essential Dynamics, and Structur3D. Since their technology is based on the melting extrusion technology, and therefore they are capable of printing cakes and macaroons, however, these firms haven't extended their business into other soft-material extrusion printers, such as pasta or pizza printers. Table II also illustrates that for the companies that are using other technologies/materials are also specialized in a very specific type of food items/materials, such as Dovetailed and FoodJet printing systems which use material jetting printers. Therefore, it can be concluded that different properties of materials require different processing technologies which drive the specialization of food printers and also the technology choices and decisions of food printer companies.

The companies in table II follow different business models. Some of them focus on consumer printers. Most of these are start-ups or companies inspired by individual researchers out of curiosity. For example, PancakeBot, whose inventor Miguel Valenzuela came up with the idea of the pancake machine from his 3-year-old daughter who wanted a pancake maker that can create all kinds of designs [34]. This company is now a partner of Storebound and still specialized in pancake consumer printers. Other companies that focus on consumer food printers include, byFlow Procusini, and Shiyin Tech. Other companies focus on industrial printers, i.e. printers for industrial users or professional kitchens. For instance, Natural Machines, Beehex, and Choc Edge. Some companies have a business model where prepacked ingredients that are sold by the company are required in order to operate the printer, e.g. Natural Machines and Choc Edge. These companies relate these bundled products to quality issues.

V. CONCLUSION

Traditional mass food preparation processes, even those with advanced processing technologies, cannot meet the demands for massive customization or personalization due to the prohibitive costs [52]. 3D printing, however, inspired and enabled food companies to experiment with alternative food preparation methods to capture and maintain market share, creating new demand for consumers with special needs. The emerging market, in turn, encourages the development in exploring printable edible materials, designing methods and novel recipes [20, 38].

The purpose of this study was to explore this aspect of 3D food printing further. Three research questions were formulated: what additive manufacturing technologies are used for 3D printing of food? What materials are being used for 3D printing of food? And, what companies are active in the process of 3D printing food and how do they compete?

It was found that there are seven categories of additive manufacturing. Out of these seven categories only four have been used in the food industry: material extrusion, material jetting, binder jetting and powder bed fusion. Interestingly, one of the generally popular methods, i.e. vat photopolymerization, is not adopted in the 3D printing of food. A main reason for this seems to be that this approach of using photo-sensitive materials is not suitable to design food [27]. However, it seem to have been used to cook egg whites [10, 21].

In terms of the materials, these seem to be mostly restricted to a few types of material such as chocolate, sugar and a few others. The main restrictions on the use of materials are printability which has to do with dimensional stability and the capability of supporting its own weight.

Fourteen companies were identified which offer 3D food printers. Out of the four additive manufacturing technologies that have been applied in the 3D food printing industry, only two are used by these fourteen companies, that is, material extrusion (85% of the companies) and material jetting. The other two technologies, i.e. binder jetting and powder bed fusion, have been used in research and development situations such as at universities and research organizations but have not yet found commercial application. The overwhelming application of material extrusion is probably due to the simplicity of the method. Previous research concluded that for food printing material extrusion is the easiest to develop and it has the widest set of foods made with it while for example material jetting is more complex and binder jetting represents the most complex food printing system [10]. Since food printing is relatively new, most of these printers have been on the market for less than five years, it is not surprising that most companies that have introduced a commercial printer have focused on a simple technology. Companies follow different business models. Some are focused on consumer-level food printers while others are looking at industrial applications. Additionally, some companies require the use of materials for the 3D printer that are sold by the company as well. Overall, the market shows a degree of specialization, i.e. companies seem to focus on a specific additive manufacturing technology and the products that can be produced using this technology. In some instances, even the product range is limited, for example to chocolate or pancakes.

3D food printing is becoming an important technology for food production and with important implications such as the ability for customized food design and personalized nutrition [20]. However, its current impact is still limited as it is viewed as complimentary to traditional food manufacturing [10, 20]. There are also only limited varieties of food items that can be printed through 3D printers. Consumer preferences in taste, quality and culture factors might also play an important role.

In terms of future technological developments, critical issues for the 3D printing of food is that the food materials need to be printable, that they are stable enough to hold the shape after deposition, and do not require further post processing. Currently, developments are already taking place to create more and better materials for food 3D printing. For example, a cookie recipe with cocoa modified material [38]. Nevertheless, a complete elimination of post-processing may not be feasible in some instances. For example, composite formulations such as batters and protein pastes may require some post-deposition cooking process as without this it will be difficult for the food product structures to retain their shapes [38]. Currently, the majority of traditional edibles fall into this category [20].

3D food printing is changing the supply chain in a similar way as additive manufacturing applications in other industries. Additive manufacturing technologies claim the advantage of less waste and less energy consumption and with the capability of faster delivery due to production closer to the customer, and at an acceptable price while utilizing fewer resources [20]. 3D food printing shares these advantages and could bring "whole" food to consumers with revolutionary shapes, tastes, colors, and texture. There are some signs that a build-to-order strategy (Just-in-time system) with low overriding cost, low inventory cost (which has been adopted by personal computer and automobile industries) is now preferred by food producers as well. Production facilities could move closer to the end customers thereby reducing transaction costs. This can potentially reshape the market structures and firms' competitiveness as well as vertical relations in the food manufacturing industry. The other feature that potentially affects firms' strategies is the vanishing tradeoff between economies of scale and scope. Food producing companies that rely on 3D food printers will be capable of producing a huge range of food items without the loss of cost efficiency. This enables small food companies to compete with large food firms in a broad spectrum of food varieties.

From a technology management point of view, there are several implications of this study. Technology management consists of six activities: acquisition, exploitation, identification, learning, protection, and selection [12]. Several of these technology management activities are particularly relevant for 3D printing of food at this point in time. Selection deals with technology and strategy (business model) decisions [12]. The study shows that the industry is in an early stage of development. Different 3D printing technologies are being pursued but there is no clear advantage of one technology. Similarly, different business models are followed such as selling printers (PancakeBot) or having subscriptions to input materials (Ripplemaker). All in all, this means, especially for new entrants, that there are many avenues to pursue in terms of technology management in this industry. For existing competitors, an important technology management aspect is to learn, i.e. to develop or acquire new technological capabilities [12]. Acquisition relates to how a company will obtain technologies this can be both internal as well as external [12]. The study has shown that the materials and methods for 3D printing food are still in an early stage. Consequently, much work is in the R&D phase which takes place at universities and research institutes. Hence, in terms of acquisition, companies that are active or plan to be active in 3D printing of food should keep an eye on the prominent universities and research institutes that are active in this field. In addition to the management of internal technology development, it is important to be aware of the latest externally developed technology as this may represent new and better ways of technology exploitation. Technology exploitation relates to generating profit or achieving other benefits from technology [12]. This is an important activity for both new entrants and existing companies. Due to the nature of the industry, there are opportunities to exploit 3D printing of food technology but, aside from technological barriers, the exploitation of technology is unclear. For instance, the fact that 3D Systems has not moved forward quickly with the ChefJet 3D printer indicates that exploitation is by no means certain. On the other hand, the situation of 'Message in a cake' indicates that there could very well be an opportunity to exploit the technology and to develop a business model. This also relates to the identification activity in technology management, i.e. to predict and forecast technological capability opportunities and threats [12]. All in all, the management of technology is critical in this early stage 3D printing of food industry. The technology is still very much in flux and the best business models are yet to be determined. The market itself, for example who will want to use 3D printers for food, the price points, and the size of the market are all unclear at this point in time. Technology management activities such as acquisition, selection, exploitation etc. are therefore crucial for existing companies as well as potential new entrants.

References

[1] M. O'Rourke, "A 3D printed future," Risk Management, May, pp. 48, 2013.

[2] J.J. Zhang, Winners and losers as 3 - D printing disrupts the market, 2013. Avaiable at: http://www.marketwatch.com/story/winners - and - losers - as - 3 - d - printing - disrupts - market - 2013 - 10 - 23.

[3] J. Horvath. Mastering 3D printing. New York: Apress. 2014.

[4] H.J. Steenhuis, "Adoption of additive manufacturing in the medical world," Proceedings of the 2016 IEEE ICMIT, pp. 304-308.

[5] S. Saunders, "Proto Labs Uses 3D Printing Technology to Bring Kitchen Prototype Inventions to Market," 3D Print.com, January 3, 2018. Available at: https://3dprint.com/199051/proto-labs-kitchen-prototypes/

[6] M.A. Parker. "Ripple Maker 3D prints images and messages onto coffee foam," 3DPrint.com, April 21, 2017. Avaialble at: https://3dprint.com/172090/ripple-maker-nitro-cold-brew/

[7] D. Bernstein. "When the Sous-Chef is an inkjet," New York Times, February 3, 2005. Available at: http://www.nytimes.com/2005/02/03/technology/circuits/when-the-souschef-is-an-inkjet.html

[8] D. Furness, "NASA wants astronauts to have 3D printed pizza, and this startup is building a printer to make it happen," Digital Trends, June 13, 2016. Available at: https://www.digitaltrends.com/cool-tech/beehex-3d-printed-pizza/

[9] M. Beetz, U. Klank, I. Kresse et al., "Robotic roommates making pancakes." Humanoid Robots (Humanoids), 2011 11th IEEE-RAS International Conference on, pp. 529-536

[10] J.I. Lipton, "Printable food: the technology and its application in human health", Current Opinion in Biotechnology, 44, pp. 198-201. 2017.

[11] A. Derossi, R. Caporizzi, D. Azzollini et al., "Application of 3D printing for customized food. A case on the development of a fruit-based snack for children," Journal of Food Engineering, 2017.

[12] D. Cetindamar, R. Phaal, and D. Probert. Technology management, Activities and tools. Houndsmills, United Kingdom: Palgrave Macmillan. 2010.

[13] J. Tidd, and J. Bessant. Managing innovation, Integrating technological, market and organizational change. 4th edition. West Sussex, United Kingdom: John Wiley & Sons. Ltd, 2009.

[14] L.G. Tornatzky and M. Fleischer. The process of technological innovation. Lexingtong, Massachusetss: Lexington Books. 1990.

[15] E.M. Rogers. Diffusion of innovation. 4th edition. New York: The Free Press. 1995.

[16] J.R. Ortt and J.P.L. Schoormans. "The pattern of development and diffusion of breakthrough communication technologies," European Journal of Innovation Management. Vol. 7. No. 4, pp. 292-302. 2004.

[17] M. Pérez Pérez, A. Martínez Sánchez, P. de Luis Carnicer and M.J. Vela Jiménez. "A technology acceptance model of innovation adoption: the case of teleworking," European Journal of Innovation Management. Vol. 7(4), pp. 280-291. 2004.

[18] D.J. Langley, N. Pals, and J.R. Ortt. "Adoption of behaviour: predicting success for major innovations," European Journal of Innovation Management. Vol. 8(1), pp. 56-78. 2005.

[19] F. Sofi, L. Ghiselli, M. Dinu et al., "Consumption of buckwheat products and cardiovascular risk profile: a randomized, single-blinded crossover trial," J Nutr Food Sci, vol. 6, no. 501, pp. 2, 2016.

[20] J. Sun, Z. Peng, W. Zhou et al., "A Review on 3D Printing for Customized Food Fabrication," Procedia Manufacturing, vol. 1, pp. 308-319, 2015/01/01/, 2015.

[21] J. I. Lipton, M. Cutler, F. Nigl, D. Cohen and H. Lipson, "Additive manufacturing for the food industry," Trends in Food Science & Technology, vol. 43, no. 1, pp. 114-123, 2015.

[22] Wohlers Associates, Wohlers Report 2014, Wohlers Associates, Fort Collins, CO. 2014.

[23] P. Verschuren, and H. Doorewaard, H. Designing a research project. Utrecht, The Netherlands: LEMMA. 2005.

[24] https://3dprint.com/

[25] www.3dprintingindustry.com/

[26] https://all3dp.com/

[27] F. C. Godoi, S. Prakash, and B. R. Bhandari, "3d printing technologies applied for food design: Status and prospects," Journal of Food Engineering, vol. 179, pp. 44-54, 2016.

[28] Diaz, J.V., Van, B.K.J.C., Noort, M.W.J., Henket, J., Brier, P., 2014. Method for the Production of Edible Objects Using Sls and Food Products. Google Patents.

[29] https://candyfab.org/

[30] J. F. Bredt, T. C. Anderson, and D. B. Russell, "Three dimensional printing materials system," Google Patents, 2002.

[31] T. Stenovec, "The ChefJet 3D printer prints dessert, and yes, it's really good," Huffington Post, January 10, 2014. Available at: https://www.huffingtonpost.com/2014/01/10/chefjet-3d-printer-food_n_4573271.html

[32] S. S. Crump, "Fast, precise, safe prototypes with FDM," *ASME, PED,* vol. 50, pp. 53-60, 1991.

[33] D. Sher, and X. Tutó, "Review of 3D food printing," Temes de disseny, no. 31, pp. 104-117, 2015.

[34] http://www.pancakebot.com/

[35] J.-P. Kruth, G. Levy, F. Klocke et al., "Consolidation phenomena in laser and powder-bed based layered manufacturing," CIRP Annals-Manufacturing Technology, vol. 56, no. 2, pp. 730-759, 2007.

[36] http://www.foodjet.com/

[37] Kira, "3D printed lab-grown meat could be in stores in the next five years," www.3ders.com. Oct 20, 2015. Available at: http://www.3ders.org/articles/20151020-3d-printed-lab-grown-meat-could-be-in-stores-in-the-next-five-years.html

[38] J. Lipton, D. Arnold, F. Nigl *et al.*, "Multi-material food printing with complex internal structure suitable for conventional post-processing." Solid Freeform Fabrication Symposium, pp. 809-815, 2010.

[39] H. W. Kim, H. Bae, and H. J. Park, "Reprint of: Classification of the printability of selected food for 3D printing: Development of an assessment method using hydrocolloids as reference material," Journal of Food Engineering, 2017.

[40] L. Hao, S. Mellor, O. Seaman et al., "Material characterisation and process development for chocolate additive layer manufacturing," Virtual and Physical Prototyping, vol. 5, no. 2, pp. 57-64, June 2010.

[41] M. Lanaro, D. P. Forrestal, S. Scheurer et al., "3D printing complex chocolate objects: Platform design, optimization and evaluation," Journal of Food Engineering, vol. 215, pp. 13-22, 2017.

[42] D. Periard, N. Schaal, M. Schaal et al., "Printing food." In: 18th Solid Freeform Fabrication Symposium, SFF 2007, pp. 564-574.

[43] C. Le Tohic, J. J. O'Sullivan, K. P. Drapala et al., "Effect of 3D printing on the structure and textural properties of processed cheese," Journal of Food Engineering, 2017.

[44] C. Severini, A. Derossi, and D. Azzollini, "Variables affecting the printability of foods: Preliminary tests on cereal-based products," Innovative Food Science & Emerging Technologies, vol. 38, pp. 281-291, 2016.

[45] A. Derossi, R. Caporizzi, D. Azzollini et al., "Application of 3D printing for customized food. A case on the development of a fruit-based snack for children," Journal of Food Engineering, 2017.

[46] D. L. Cohen, J. I. Lipton, M. Cutler *et al.*, "Hydrocolloid printing: a novel platform for customized food production." In: 20th Annual International Solid Freeform Fabrication Symposium, SFF 2009, pp. 807-818.

[47] L. Di Leo, "Pasta of the future?" Unpublished. Available at: https://www.barillagroup.com/sites/default/files/Cs%20Barilla_focus%20Pasta%203d-EN_rev.pdf

[48] https://www.google.com/patents/WO2015115897A1?cl=en

[49] http://www.chloerutzerveld.com/edible-growth-2014/

[50] M. Wolf, "It's alive! 3D Systems partners with CSM to bring ChefJet 3D food printer to market," August 20, 2017. Available at: https://thespoon.tech/its-alive-3d-systems-partners-with-csm-to-bring-chefjet-3d-food-printer-to-market/

[51] http://www.messageinacake.de/

[52] A. Zoran, and M. Coelho, "Cornucopia: the concept of digital gastronomy," Leonardo, vol. 44, no. 5, pp. 425-431, 2011.