Business models for the 3D food printing industry

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LICENTIATE THESIS

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Abstract

3D food printing is a fascinating novel technology with many promising applications, from futuristic-looking food to personalized nutrition, and space food for astronauts. However, much of its potential is only realized in the laboratory or speculated in the literature. This research is an attempt to explore the barriers to the diffusion of this new technology to the wider market. It argues that the choice of the business model plays as important a role as the technical characteristics of the technology itself. By using both the concept of business model innovation and product innovation, some of the barriers could be first better understood, reduced, and overcome.

The research consists of findings from two studies presented in two appended papers. The first study is qualitative research that provides a stock of what business models are being used to commercialize 3D food printing technology. The second study explores the possibilities of using business model innovation to reduce the barriers to new technology diffusion in a new market.

The research contributes to the empirical knowledge of business and economic aspects of 3D food printing technology. It contributes to the field of business model research by complementing empirical studies of business model innovation in the context of novel technology. The comparisons of business model patterns in 3D food printing could be generalized and applied to make similar comparisons between industries. Further research can focus on the experiment with the integration of business model innovation and product development, including the design, testing and evaluation phases.

On the managerial side, the business model patterns could serve as a starting point for companies looking for a way to innovate the business model in new directions. Replication of proven and functioning business models may reduce risk and development time.

Key words: 3D food printing, 3DFP, Additive manufacturing, Business model innovation, Business model pattern, New technology

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Terminology and abbreviations

3DFP, 3D food printing

AHC, agglomerative hierarchical clustering

AM, additive manufacturing

CAD, computer-aided design

FDM, fused deposit modelling

MDS, multidimensional scaling

UPGMA, unweighted pair group method with arithmetic mean

Abstract

3D food printing is a fascinating novel technology with many promising applications, from futuristic-looking food to personalized nutrition, and space food for astronauts. However, much of its potential is only realized in the laboratory or speculated in the literature. This research is an attempt to explore the barriers to the diffusion of this new technology to the wider market. It argues that the choice of the business model plays as important a role as the technical characteristics of the technology itself. By using both the concept of business model innovation and product innovation, some of the barriers could be first better understood, then reduced, and overcome.

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Lund, 2022

Nanond Nopparat

Appended papers

The research presented in this thesis comprises two papers that are listed below. The list also includes a description of the author's contribution to each paper. A summary of each paper can be found in Chapter 4, while the full version of each paper is appended at the end of the thesis.

Paper 1:
Nopparat, N. and Motte, D. (2022). Business model patterns in the 3D food printing industry.

Status: Manuscript under revision with International Journal of Innovation Science.

Author contribution: Nanond Nopparat contributed to the research design, data collection, and writing of the initial version of the text. Damien Motte contributed to quantitative data analysis and critically reviewed the text. Both authors were responsible for the data analysis as well as the interpretation and discussion of the results, and the refinement of the text.

Paper 2:
Nopparat, N. and Motte, D. (2022). The influence of business model on the development of 3D food printing technology for dysphagia patients in elderly care. Published in the Proceedings of the International Conference of Additive Manufacturing for a Better World, 2022, Singapore (peer-reviewed) in Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2022.09.028

Author contribution: Nanond Nopparat contributed to the data collection, research design and analysis. Damien Motte contributed to the refinement of the discussion and provided critical revisions. Both authors were responsible for the writing of the text.

1. Introduction

Additive manufacturing (AM) technology has been around for more than three decades. There are abundant applications for this technology. The word 3D printing has almost become a household name.

3D food printing, however, is still in its infancy. Although the technical aspect is fundamentally no different from its older cousins, there are some things that are unique to this application. These differences are enough to make the diffusion of the technology far lower than technology such as metal or plastic AM.

This thesis attempts to explain this low diffusion and suggests ways to break the barrier.

1.1. Background

Additive manufacturing (AM) is a technology known for its ability to create complex geometry with almost no limitations. The technology has been widely applied across different industries and at different levels of complexity, ranging from homemade toys to space exploration. AM technology has contributed to the customization and personalization of products such as various kinds of implants used in healthcare. The complex geometry parts are usually as strong as, if not stronger than, the equivalent parts made from the more traditional manufacturing methods with the added benefit of being much lighter. The resulting weight-saving has benefited the aerospace and automotive industry enormously.

However, not all technologies were not born equal. When AM is applied to food processing, known as 3D food printing (3DFP), the usage is still limited. This does not mean that the potential benefits of 3DFP are small. On the contrary, it has been proposed that the possibility of customization alone can already improve the health of the consumer significantly (e.g. Sun *et al.*, 2015). The complex shapes and forms that can be created by 3DFP open the way to almost endless opportunities to attract customers (Sun *et al.*, 2018). Since the market introduction of the first functional 3D food printers in 2006 (Malone and Lipson, 2007), research and development in the field have explored tailored nutrition, texture, and consistency (Sun *et al.*, 2015; Yang *et al.*, 2017; Mantihal *et al.*, 2020; Burke-Shyne *et al.*, 2021; Recuero-Virto and Valilla-Arróspide, 2022) resulting in applications such as the production of personalized meals such as more appealing food for the elderly in hospitals (Chua *et al.*, 2018; Lipton *et al.*, 2015b), for astronauts on space missions (Terfansky and Thangavelu, 2013) and generally the possibility of creating edible printed material with extraordinary designs (Mantihal *et al.*, 2020). These benefits are already there to be captured but some barriers are yet to be overcome.

One of the barriers is the technology itself. Arriving relatively recently, it was first described in a patent by Nanotek Instruments in 2001 (Yang *et al.*, 2001), 3DFP still lags behind its more advanced counterparts such as metal or plastic AM technologies. Primarily among the technological challenges, the current printing speed of food items is rather slow which reduces the number of possible applications (Burke-Shyne *et al.*, 2021). There is considerable complexity in the development of food formulations as a printing material due to their required physical properties (Wendin *et al.*, 2010). There are also economic challenges such as the high cost of equipment and specialized food ingredients, and constraints on transportation and storage of the raw material and printed food (Burke-Shyne *et al.*, 2021). Moreover, because of customers' unfamiliarity with 3DPF and 3D printed food items (Cardello *et al.*, 2007) they have concerns such as safety and hygiene in relation to 3D printed food.

In addition, this thesis argues that the business model is another important barrier to 3DFP diffusion. While the mentioned technological challenges represent real hurdles for the continued diffusion of 3DFP they could be overcome or bypassed using a suitable business model. The role of a business model is to create value, then deliver and capture it from an established or emergent technology (Chesbrough, 2010). Thus, a functioning business model may speed up the diffusion of emergent technology. 3DFP is at present available to individual users for recreational purposes, and some more capable machines are used for small-scale food production in restaurants, confectionery, and pastry shops (Mantihal et al., 2020). Overall, the application of large-scale 3DFP remains low (Le-Bail et al., 2020; Mantihal et al., 2020), falling short of the widely adopted industrial-scale 3D printed production in many industries.

One way to speed up the diffusion of 3DFP is to develop a business model which will create and deliver customer value as well as capture value for the producer. However, research interest in suitable business models for 3DFP has so far been very limited (Rayna et al., 2015; Ramundo et al., 2020). A couple of cases of business models related to 3DFP have been reported by Flammini (2017) and Jia et al. (2016), but there is neither a systematic study of business models used in the 3DFP industry nor any study of how successful the business models are in diffusing the 3DFP technology. Such a study could be valuable for both the research on 3DFP and related business models as well as for business model research in general.

1.2. Research questions

Given the scarcity of research knowledge of business models in the 3DFP industry and how the business models in use affect the diffusion of 3DFP this thesis will address the following research questions:

RQ 1 What are the business models used in the 3D food printing industry?

RQ 2 In what way can business model innovation be used to facilitate the diffusion of 3D food printing technology?

1.3. Research focus

The research reported in this thesis focus only on business models related to 3DPF for oral consumption. 3D printing of food materials for other purposes, such as purely for decoration, is not within the scope of this research.

1.4. Thesis outline

This thesis is structured as follows: Chapter 2 introduces the frame of reference, including the description of 3D food printing technology, the concept of the business model, and business model innovation. Chapter 3 presents the methodology, the research design, and the limitations. It also provides a description of a research project, Future Meal project, which forms the basis of paper 2. Chapter 4 summarizes the objectives, main findings, and implications of the appended papers. Chapter 5 discusses the findings, research contributions, further research and implications for managers.

2. Frame of reference

This chapter describes the fields of research and the theory applied to this research which is presented in two parts. In the first part, it introduces AM technology for food processing. The second part deals with the concept of business models, and business model patterns as an analytical tool.

2.1. 3D food printing

3DFP is the application of AM to food processing. Apart from the realm of science-fiction, one of the first mentions of a machine that can deposit food material using AM technology is a patent filed in 2001 (Yang *et al.*, 2001). It was not until 2006 that Fab@Home became the first commercially available 3D printer capable of depositing food material (Malone and Lipson, 2007). Around the same time, Evil Mad Scientist Laboratories' Candyfab sugar printer series also arrived on the market. Technically speaking, these early machines were 3D printers that used food as their printing material which possessed many attractive properties such as being easily accessible, at a relatively low cost, as well as being naturally biodegradable (Periard *et al.*, 2007). The primary goal of early research into printing with food material was to make the technology more accessible by lowering the cost of printing material (Wegrzyn *et al.*, 2012). When desktop 3D printers and abundant low-cost printing materials such as plastic filament for fused deposit modelling (FDM) 3D printers became available, the attractiveness of printing with food paste or granulated sugar began to fade away. The developer of Candyfab sugar printer considered it had served its purposes and discontinued the development in 2009. Fab@home lived on as a multi-material, multi-purpose 3D printer, available through open-source (Lipton *et al.*, 2011).

The process of 3DFP is similar to that of any AM technology. It starts with a 3D computer-aided design (CAD) model of the object which is digitally sliced into thin layers (Dankar *et al.*, 2018). The sliced digital model is then transformed into a physical object by a 3D printer depositing the material layer by layer. The most common material deposition method used in 3DFP is extrusion, during which material is dispensed through a nozzle (Mantihal *et al.*, 2020). Other methods include, material jetting and binder jetting, are also used in a small number of 3DFP technologies. With material jetting, droplets of build material are selectively deposited, while droplets of liquid bonding agent are deposited to join powder build material in the binder jetting method (Mantihal *et al.*, 2020). See figure 1 for the schematic of 3D food printing.

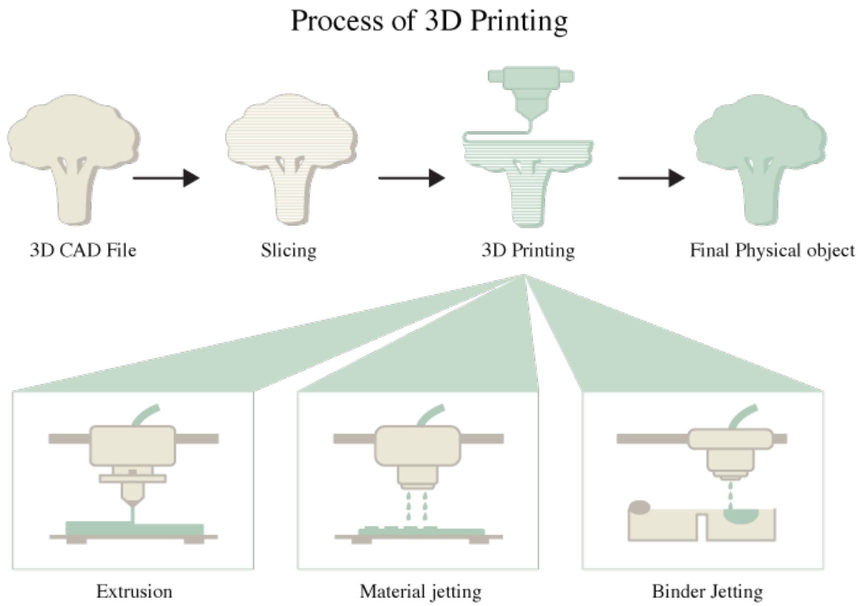

Figure 1. Visualization of the basic principle of 3D printing and deposition methods commonly used in 3DFP

At present, 3D food printers are becoming more user-friendly and easier to navigate (Dick *et al.*, 2019) e.g. with touch screens and Bluetooth functionality. Most 3DFP started using chocolate or sugar powder as their food printing material, later followed by gelatin and dough (Mantihal *et al.*, 2020). A number of food additives, such as glycerol, lecithin and potato starch, are used to enhance the flowability and printability of the food printing material (Mantihal *et al.*, 2020). Adding nutrients to the printing material increases the wholesomeness of the 3D printed-food products (Severini and Derossi, 2016). Along with the development in the industry, the research front has been very active and the quantity of research on 3DFP is on the rise (Jemghili *et al.*, 2021), with the research into the printability of different food ingredients and the print accuracy being two of the prominent streams. In addition, the perception of consumers toward the food produced by 3DFP has received considerable attention (e.g., Lupton and Turner, 2018). The unique ability to create complex food structures opens the way to the possibility to create new food perceptions, by altering food structure or appearance.

In terms of commercial diffusion, 3DFP is still in the early phase dominated by users in three different markets: household users, small-scale food producers and industrial-scale food producers (Mantihal *et al.*, 2020). The household user market is dominated by relatively cheap and uncomplicated machines, such as the above-mentioned Fab@Home machines, mostly for printing customized chocolate and sugar food items (Sun *et al.*, 2015). Using open-source software and open content the household user can easily access digital blueprints for new designs as well as modify and create new designs themselves. The small-scale food producers consist mainly of restaurants, cafés and bakeries that use 3DFP to customize products, adding artistic and gourmet style value to their products (Lipton *et al.*, 2015a). The industrial-scale food producers' use of 3DFP is still in its infancy with the hospitality industry as the main candidate for being an innovator customer (Mantihal *et al.*, 2020). The use of 3D food printers to produce easy-to-swallow food for the elderly suffering from dysphagia is one of the applications made possible by 3DFP (Chua *et al.*, 2018; Lipton *et al.*, 2015b). Moreover, meals with personalized nutrition based on consumer-specific data can be made with 3DFP to better tailor the nutrition intake to the individual (Lipton, 2017). Outside the hospitality industry, there are also research efforts to improve drug-release characteristics in the pharmaceutical industry (Dumitrescu *et al.*, 2018). Even space exploration could benefit from 3DFP by providing the astronauts with food of improved texture and nutrition (Jiang *et al.*, 2020; Terfansky and Thangavelu, 2013).

However, despite over three decades of existence and much progress in developing the technology, much of the commercial potential thought to be possible with 3DFP has not been realized (Mantihal *et al.*, 2020). Thus, we now turn to the topics of business models, business model innovation and business models in the 3DFP industry.

2.2. Business model and business model innovation

From the value perspective, a new technology, in itself, has no economic value (Chesbrough, 2010). The economic value of new technology is latent until it is commercialized through a business model (Chesbrough, 2010). The same technology, being commercialized through two different business models, will economically perform differently. Thus, a business model can be understood as a mediating construct that connects technology development to economic value creation. The two core functions of a business model are value creation and value capture (Johnson *et al.*, 2008). The former describes how a firm performs activities to create products and services that generate value for everyone involved in the activities. How the firm creates economic return is described by the value capture. (Chesbrough, 2010) emphasizes the importance of the net created value which is what attracts suppliers, partners, and customers, while the captured economic value is necessary for the survival of the firm.

A business model is necessary to discover a path to the market, thus enabling a new technology to deliver value to the customer. According to Abdelkafi *et al.*

(2013, p. 12), *a business model describes how the company communicates, creates, delivers, and captures value out of a value proposition*. The business model is a holistic concept that underscores the importance of firms in not only developing their own resources and capabilities, but also to collaborates in an ecosystem of partners (suppliers, customers, development partners, public organizations etc.) and providing complementarities (other products, technologies, or services) for the commercialization of a new technology (Zott *et al.*, 2011).

Innovation is normally defined as new products or new processes that have been successfully implemented and/or diffused into the market (OECD, 2018). In the last 15 years or so, a new source of innovation has been introduced, business model innovation, complementing the traditional product and process innovations (Zott *et al.*, 2011; Foss and Saebi, 2017). Research in business model innovation has been growing rapidly over the last decade (Foss and Saebi, 2017). Four major research streams have been identified by Foss and Saebi (2017) in their review i.e., conceptualization and classification of business model innovation, business model innovation as a process, business model innovation as an outcome, and business model innovation as organizational implications/performance.

While the research literature offers several somewhat different definitions of business models, the research literature agrees that business model innovation entails non-trivial changes in the current business model (Foss and Saebi, 2017). Here the author builds on Abdelkafi *et al.* (2013)'s definition of a business model, see above, and related definition of business model innovation: *A business model innovation happens when the company modifies or improves at least one of the value dimensions* Abdelkafi *et al.* (2013, p. 13). Thus, when a company changes its way of communicating, creates, delivers, and captures value out of a value proposition it will be regarded as a business model innovation.

Business model innovation as an outcome, i.e., new and innovative business models, has been researched in many industries such as the electric mobility (Abdelkafi *et al.*, 2013), newspapers (Karimi and Walter, 2016) and aviation (Schneider and Spieth, 2013) to name a few, but also for particular types of new business models such as for sustainable energy (Richter, 2013) and servitization (Kindström, 2010). Business model innovation research has also shown interest in the AM industry such as the studies by Holzmann *et al.* (2019) and Rayna *et al.* (2015), including the 3DFP industry (Flammini *et al.*, 2017). Most of the research in this stream is descriptive i.e., describing new and innovative business models in specific contexts, but generally not relating them to performance or organizational implications (Foss and Saebi, 2017).

Business model innovation often strongly challenges the current resources and capabilities as well as organizational processes and leadership in the company (Teece, 2010). The research stream business model innovation and processes describe and analyze different stages of the business model innovation process, (e.g., Frankenberger *et al.*, 2013), required capabilities and processes to support the change process (e.g., Achtenhagen *et al.*, 2013), the importance of experimentation and learning (Sosna *et al.*, 2010), as well as companies' failures of business model innovation such as the case of Polaroid (Tripsas and Gavetti, 2017).

While a business model can serve as a management tool to commercialize a technology it may also be used as an analytical tool to understand how firms adapt to new technological challenges. By describing them with their business models, companies' unique and complex processes of creating, communicating, delivering, and capturing value from their value position can be understood and compared. Thus, it is important to review the research contributions of business models and business model innovation in the 3DFP industry.

2.3. Business model and 3D food printing technology

Although the connection between AM technology and its business models has attracted the attention of prior research (e.g., Holzmann *et al.*, 2019), studies on business models for 3DFP are scarce, i.e., limited to two studies in her dissertation, Flammini (2017) surveys the business models that emerge when 13 companies commercialize 3DFP. She finds that most companies develop business models aiming for a niche market, they experiment with temporary business models while developing the technology and the customers, and they use both input from customers to develop their business model as well as license components (such as software) to the collaboration partners. Overall, she finds that the 3DFP companies experiment with their business models including which external partners and complementarities to work with. One of the cases has been published in Flammini *et al.* (2017). Jia *et al.* (2016) investigated the business models of different actors involved in the value chain of a 3D chocolate printing technology. The study, a simulation of two business models, one manufacturer dominant and one retailer dominant, showed that 3D chocolate printing has the potential to generate value for early technology adopters and change the relationships between players within the supply chain. These early studies illustrate the important role business models and business model innovation can have when commercializing 3DFP technology.

2.4. Business model patterns

One approach to the study of business models in an industry is to consider business model patterns (Abdelkafi *et al.*, 2013). A business model can be broken down into components such as value proposition, value creation, and value capture, each of these components representing the key activities performed by the organization. The activities or combinations of activities observed across several organizations form what is called business model patterns which can potentially be applied to other businesses and are expected to deliver similar effects. One distinguishes mainly between so-called prototypical business models that holistically describe industry-specific business models and business model solution patterns (solution patterns for short) that are reoccurring combinations of business model elements (Malone *et al.*, 2006). Several researchers have gathered business model patterns from different industries including AM. The two patterns found in the AM industry by Holzmann *et al.* (2019) were the "low-cost online business model" (with the general value proposition of providing quality printers at low cost) and the "technology expert business model" (with focus on expertise, innovation leadership and quality). However, as also noted by Rayna *et al.* (2015), business model patterns for the 3DFP industry have not been included in the previously identified ones. The business models that are successfully used with non-food 3D printing technology are not necessarily compatible with the technology for food production, one reason being that 3DFP possesses some unique challenges, including food formulations development, transport and storage, hygienic requirements and sensory attributes experienced by the consumer.

As reviewed above there are two prior studies that have investigated business model patterns in the 3DFP appearing after 2015, i.e., Flammini (2017) and Jia *et al.* (2016). In relation to Holzmann *et al.* (2019)'s finding of two patterns, i.e., "low-cost online" and "technology expert", Flammini (2017) in her study of 13 3DFP companies identifies three business model archetypes in the industry: 1) product provider, i.e., developing and selling the 3D food printer, 2) knowledge service provider, i.e., research and consultancy companies, 3) competence assembler i.e., a 3DFP franchised and pop-up restaurants. The most common archetype was the product provider followed by the knowledge service provider. The last archetype, the competence assembler, was represented in only one case. The company tried to commercialize 3DFP through pop-up restaurants, e.g., at private parties, festivals etc, and provide a platform for other 3DFP companies in franchised restaurants. Jia *et al.* (2016)'s study of two variants of the product provider business models in the chocolate 3DFP industry, one selling the food printers mainly to food producers, and one selling the food printers mainly to retailers and simulated the profit and growth effects on the supply chain in the two variants of the producer provider business model. Thus, both Flammini (2017) and Jia *et al.* (2016) demonstrate that there are differences between the business model patterns identified in the AM industry and the ones identified in the 3DFP. For example, the low-cost online business model does not seem to exist in the 3DFP industry. This might be due to the unique characteristics of the food industry and/or that the 3DFP is a later development than its "cousins" in plastics and metals.

In summary, this chapter has introduced the frame of reference and the concepts used in this thesis. The origins, challenges, and benefits of 3DFP have been reviewed. In addition, the concepts of business models and business model innovation have been defined and its role as a mediator between new technology and commercialization have been discussed. The studies of emergent and established business models in use, i.e., business model patterns, have been presented with a focus on prior studies on business model patterns in the 3DFP. Overall, there are limited studies of business model patterns in the 3DFP. The limited number of studies combined with the rapid technology development calls for additional studies.

3. Methodology

This chapter describes the approach and research methods used in the exploration of the research topic.

3.1. Research process

This research is divided into two parts, each resulting in a paper, see Figure 1. First, an explorative study was used to understand the landscape of the 3DFP industry, from the point of view of the business models used by manufacturers, which resulted in Paper 1. Paper 2 is a result of the author's participation in a research project named Future Meal which provided an opportunity to observe the parties involved in the project. The business model framework developed in Paper 1 was used to describe the setting in Paper 2, as well as the proposed solutions.

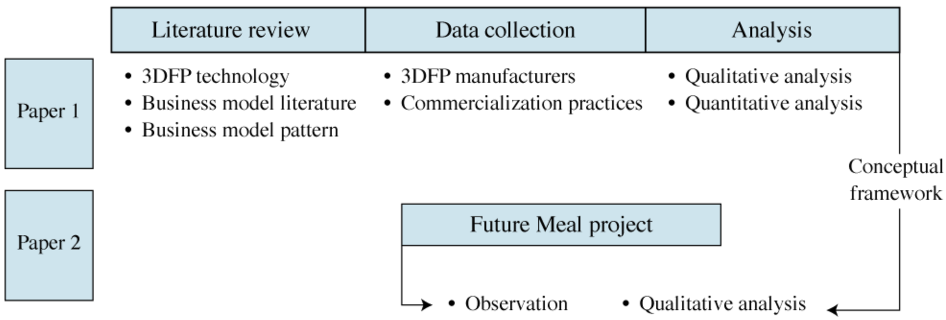

Figure 2. Overview of the research process

The methodology used in paper 1

Paper 1 is a quantitative explorative study, aiming at identifying distinct business model patterns used in 3DFP. Cluster analysis was chosen as an appropriate statistical analysis tool. The tool has been used to identify business model patterns in different industries, including AM (Holzmann *et al.*, 2019) and sharing business models (Curtis, 2021).

Since the aim of the paper was to analyze the business model, it was decided to focus on the manufacturers of 3DFP technology that have commercialized one, or more, models of their product. The manufacturers were identified as the more prominent group leading the way in the industry. With the number of companies available, it was thought that they would provide a meaningful view of the industry. The data collection began with a collection of 3D food printers and manufacturers available in the literature. This was supplemented by the search for additional manufacturers on the internet, including product reviews and advertising materials. The product's specifications, as well as the information required for the business model analysis, were obtained primarily from webpages of the selected companies. In the end, 24 3D food printer manufacturers were selected for further analysis.

The first part of the analysis involved the identification of prototypical business models based on the 16 business model archetypes proposed by Malone et al. (2006). The analysis tool was based on the value-based, five-component business model framework proposed by Abdelkafi et al. (2013). The tool registered each company's practice of commercializing their 3D food printers as binary data, where 1 indicates that the action is performed and 0 indicates that it is not performed.

The quantitative research method was used to identify the business model patterns. An agglomerative hierarchical clustering (AHC) technique was used to identify the possible association between business model configurations that form a discernable pattern.

The methodology used in paper 2

Paper 2 was intended to propose viable business model solutions to the setting encountered in the Future Meal project. The paper is based on the experience during Future Meal project in which the author took part. The description of the project can be found in section 3.2.

Based on the observation from Future Meal project, the business model framework developed in Paper 1 was used to describe the relationships between the parties involved with a business model. The proposed business model alternatives were based on the literature on technological innovation and their business models.

3.2. The future meal project

During the course of the research, the author was involved in a research project called the Future Meal project. Funded by Sweden's innovation agency (Vinnova) and coordinated by the Research Institutes of Sweden (RISE), the two-year research explored the possibility of using 3DFP in Swedish elderly care which was represented by two participating municipal kitchens. The project was broken down into small work packages each exploring different aspects of using the technology, from the development of printing material, print parameter, business model, and the perception of the kitchen staff and the elderly toward the use of the technology.

The author was involved in the work package exploring viable business models as one of the team members from the department of design sciences, LTH, Lund university. The project served as the bridge between research question 1 and research question 2. On the one hand, it provided insight into the business model that the 3D food printer manufacturer was using. It confirmed the dominating business model patterns identified in paper 1. On the other hand, the setting provided a starting point from which business model alternatives were proposed in paper 2.

The purpose and scope of Future Meal project

The Future Meal project ran for two years, between 2018 and 2020. The primary goal of the project was to investigate the possibility of using 3DFP technology to produce food for the elderly suffering from dysphagia or difficulty swallowing (World Health Organizatìon, 2019). Dysphagia is caused by motoric dysfunction (mainly neuromuscular disorders) or narrowing of the esophagus, resulting in disturbance in the transport of food to the stomach (Wolf, 1990).

The project members on the academic side came from universities in Skåne region in Southern Sweden, Lund university included, and the researchers from RISE. The Swedish elderly care was represented by two municipalities, Helsingborg and Halmstad. The project also partnered with two food suppliers and one 3D printer manufacturer.

The findings from Future Meal project

The project team was able to demonstrate the possibility of using 3D printing technology to recreate food ingredients with a high level of complexity and details of the natural food. In addition, the elderly participating in the user test had more positive responses to food prepared by a 3D food printer than expected. The responses from the nurses in charge of the dysphagic elderly were also positive. Only the relatives of the elderly expressed some skepticism towards the technology.

The project did reveal many technical challenges to be overcome before the technology could put food on the table. Much remains to be done on just creating suitable printing material mixtures and scaling up the production process. The deposition speed of extrusion technology is notoriously slow, resulting in a low production rate. Adapting the printing processes for different food materials is also largely a trial-and-error process. Although the need for special meals for the dysphagic elderly represents just a small portion of the food prepared daily by the kitchen, the current 3DFP technology is still too slow to economically replace the manual food preparation process. More technological development is needed but in order to proceed, a viable business model is required.

3.3. Reflection on research quality

The quality of research is often discussed in terms of four design tests i.e. construct validity, internal validity, external validity, and reliability (Yin, 2014). Construct validity concerns the operational measures used, internal validity is related to establishing of casual relationship, external validity defines the generalization from the study's findings, and reliability covers the degree of reproducibility of the study (Yin, 2014). This section discusses how the author tried to address each of these tests in this research.

To ensure construct validity, In Paper 1, the list of 3DFP manufacturers was obtained from a review of the literature on 3DFP. The list was supplemented by both authors separately searching on the internet for additional companies not covered by the literature. The choices of business model configuration options used to represent the business practices of each company were based on the literature on business model patterns for AM industry (Holzmann *et al.*, 2019), as well as the business model component literature (Remane *et al.*, 2017; Osterwalder and Pigneur, 2010), with technical characteristics coming from the 3DFP literature (Godoi *et al.*, 2016; Wegrzyn *et al.*, 2012; Mantihal *et al.*, 2020; Lipton *et al.*, 2015a). To the list, the authors added two business model configuration options.

The low number of studied companies potentially affects the external validity in that it limits how much the findings can be generalized to the 3DFP industry in general. However, with the fact that 3DFP is a new industry and a significant portion of its manufacturers have emerged only recently, it is believed that the 24 companies found are a good representation of how the industry was during the period of this research.

Reliability of Paper 1 is achieved through the documentation and detailed explanation of how the data is collected, the analysis is performed, and the result is interpreted. The raw data is made available to the audients. The cluster analysis is made robust by triangulation with three cluster analysis techniques.

4. Summary of appended papers

4.1. Paper 1: Business models in the 3D food printing industry

Objectives

Present for more than three decades, 3DFP technology has not experienced the same widespread adoption as its non-food counterparts. It is believed that relevant business models are crucial for its expansion. The purpose of this study is to identify the dominant prototypical business models and patterns in the 3DFP industry. The knowledge gained could be used to provide directions for business model innovation in this industry.

Findings

All identified 3DFP businesses use the prototypical business model of selling ownership of physical assets, with some variations. In addition, low-cost 3D food printers for private usage and dedicated 3D food printers for small-scale food producers are the two primary patterns identified. Moreover, several benefits of the 3DFP technology are not being utilized and the identified manufacturers are barely present in high-revenue markets, which prevents them to drive technological innovation forward.

Implications

The results can be used as a canvas for existing companies desiring to renew their business models or for new companies willing to enter the market.

4.2. Paper 2: business model alternatives for 3D food printing in Swedish healthcare

Objectives

Paper 2 looks at Future Meal project and describes the difficulty of implementing the 3DFP technology encountered during the project from the perspective of the business model.

Findings

One of the findings is that the manufacturer business model pattern, one of the dominating business model patterns identified in paper 1, was also used by the 3D food printer manufacturer involved in the project. The business model was not suitable for the technical characteristics of the 3D food printer used which became another barrier to the implementation of the technology.

The paper presents several business model alternatives and highlights the often-neglected role business models have in enabling and guiding the further technological development of 3DFP technology. The link between business models and technological development is highlighted in other industries where AM has not taken off or has not been widely adopted yet.

Implications

This study highlights the fact that business models have for some market segments a crucial influence on the development of technology. Business models help or hurt technological advances, and different business model types lead to different directions in technology development. The situation encountered by the Future Meal project is not unique to the 3DFP technology. It is a situation where a new and promising technology does not fit well into the main business model of the intended market.

5. Concluding discussion

This chapter summarizes and discusses the main findings centered around the following research questions raised in Chapter 1:

1. What are the business models used in the 3D food printing industry?

2. How can business model innovation be used to facilitate the diffusion of 3D food printing technology?

The discussion contributes to the understanding of the current business model patterns used within the 3DFP industry, the links between the technology and business models, as well as the research contributions and the implications for managers and entrepreneurs in the 3DFP industry and future research.

5.1. The business model landscape of the 3D food printing industry

Although an increasingly popular topic in the research field, 3DFP is still a relatively new industry, especially when compared to the more mature AM applications. There are a limited number of players from the manufacturer side, some of which are large, well-established firms, while others are smaller players entering the market. From these manufacturers of 3DFP technology, an even smaller number have been able to put one or more of their products on the market, 24 of which have been identified in this research. By investigating the characteristics of their products and the practices they used to commercialize them using the business model pattern analysis tool, two dominating prototypical business model patterns (cf. Malone *et al.*, 2006) were found. In addition, a few other business model patterns were also used by some manufacturers.

The main prototypical business model pattern identified is the manufacturer business model in which companies generate revenue primarily through the selling of manufactured 3D food printers. The companies working with this business model develop and sell the physical asset, the 3D food printer. This is the same prototypical business model, in her terminology called producer provider, which Flammini

(2017) identified in her study of 13 3DFP companies. It is also the business model followed by the case company in Jia *et al.* (2016)'s study of a chocolate food printing company. This business model pattern is observed in the manufacturers that have previously produced other types of non-foods AM technology.

A large segment of 3D food printer manufacturers identified in this prototypical business model is represented by the manufacturers who primarily produce low-cost 3D printers aimed at individuals for personal usage, resembling the largest cluster of prototypical business models in the AM industry (Holzmann *et al.*, 2019). These companies do not just appear out of nowhere. They are manufacturers that have already established themselves by producing non-food 3D printers of similar characteristics. The type of 3D printer that yields itself well to printing with food material is the extrusion-based printer. With little modifications, thick paste or melted chocolate replaces plastic filament and the printer is ready for the new application.

Business model-wise, this expansion into a new market does not require even the slightest change to the manufacturer's original business model. The manufacturers utilize their existing manufacturing capability, the distribution and sale channels are unaltered, and the customer segment, household users, is also not changed. From the point of view of the manufacturers, their action is very logical, based on their strength, capitalizing on the market segment they are familiar with. There are many good reasons to resist the change of business model. For one thing, the business model has been successful as far as the manufacturer company is concerned. That prior success creates barriers to business model innovation has been observed many times in the innovation management literature, such as in the disc drive industry (Christensen, 1997) and in individual large companies such as Polaroid (Tripsas and Gavetti, 2017) and IBM (Kaplan, 2008).

When entering a new market with a slightly different product offered to a new group of customers, it is easy to think that if anything needs to be changed, it is only the product being offered. It is difficult to see that perhaps it's the business model that needs changes and even more difficult to undertake such changes. Tripsas and Gavetti (2017) in their study of Polaroid's failure to commercialize the digital camera, point to the rigidity of managers' thinking about the business model and the costs and difficulties of developing new capabilities needed for a change in the business model, as two major barriers towards business model innovation. However, in this study, it is not known if the surveyed 3DFP companies are even aware that the business model can be changed or have attempted to do so.

The second most common prototypical business model among the surveyed 3DFP companies is the manufacturer-contractor cluster, companies that primarily sell services related to 3DFP. In addition to offering value proposition and value capture based on the sale of 3D food printers alone, these companies benefit from the printed materials and offering the 3D printed food as a product. This is similar to the second most common prototypical business model identified by Flammini (2017) which she called the knowledge service provider. This business model is dominated by new companies and startups specifically focused on 3DPF. They predominantly target small-scale food producers, such as bakeries and restaurants. Their printers are designed to print with specific food materials available from the company, providing an additional source of revenue.

In addition, 3D-printed food, customized and made-to-order, ready for consumption or the catering service offering experience in 3DFP technology are yet more examples of what is being explored in this market. Just like what happened to plastic and metal AM technology that came before, the 3D food printer has become a tool for manufacturing. The manufacturer-contractor business model also has a different sales model compared to the dominating manufacturer model. While the latter primarily sells through distributors and retailers, the manufacturer-contractors primarily sell through online shops. The blooming of emerging companies in this area does not necessarily guarantee success in the long run. However, with much of the potential of 3DFP believed to be untapped, the multiple paths being explored are very promising. For one thing, it is a market segment that does not yet have a well-established player yet.

The fact that new companies and startups often are the ones that creates new business models for new technologies, even when the new technology is developed by an incumbent company, has been described by several innovation management researchers, e.g., Chesbrough and Rosenbloom (2002) in their study of Xerox and its technology licensing after failing to commercialize their patents themselves, and the case of commercializing digital cameras (Tripsas and Gavetti, 2017). Companies that are designed to commercialize the new technology seem to have an advantage over established companies that already operate under an established business model. While the study in paper 1 cannot provide any insights into the specific explanations of the new companies' ability to break-away from the dominating manufacturer model and create a new business model based on services to their customers, the most common explanation in the research literature is a combination of new ways of thinking by managers and/or entrepreneurs and access to related capabilities needed for the new business model. In the 3DPF case, the manufacturer-contractor cluster of companies probably have more expertise regarding different food materials and how it behaves in the printing process than the dominating manufacturer cluster.

Perhaps a bit surprising, given the indication in prior research of the opportunities in health and nutrition applications (e.g., Mantihal *et al.*, 2020), few companies exploit these applications. Only two companies show the use of personalized nutrition in their value propositions. Overall, the variation of the value propositions in the business models, given the 3DFP technology's possibility to use freshness, texture, mixing of food materials, creative designs, nutrients, and much more, seems limited.

In terms of value capture the two prototypical business model patterns show the difference between a selling a physical asset via a distributor business model and a direct selling and razor-and-blade business model (Gassmann *et al.*, 2014). The razor-and-blade business model, consisting of a basic unit and some kind of necessary supplement, is common in many industries such as printers, shavers, computer games, mobile phones etc. Often the basic unit, e.g., the printer, is priced low, and the supplement material, e.g., food material, is priced high, as the customers are locked-in and have difficulty finding other sources of compatible supplement material. Apart from this difference, there is only one company applying a leasing model, leasing their printers to their customers, instead of selling the printers. Another possible value capture model would be licensing, printer technology, food material, designs etc., but this does not seem to be used yet.

The survey of the business model patterns indicated an evolution of business models in 3DFP. A first wave of pioneering companies used the manufacturer business model focusing on proven technology, low-cost and home users. A second wave of companies, primarily new companies, associated with newer generations of 3D food printers, targeting small-scale producers, providing services to their customers in the form of pre-packaged food materials. Thus the business model evolution goes from product offerings to service offerings (Neely, 2008; Flammini, 2017). The few companies offering personalized nutrients and leasing might form a third wave of business model evolution targeting new needs and niche markets.

This research has discussed situations where technological development was based on a preconceived business model. Now, the author wants to point to a slightly different situation in which a business model or business models are consciously selected before the beginning of the product development cycle. It can be one of the requirements. Put another way, *Business model choice influences technological and firm development, but it is pertinent to ask if technology also acts on business model possibilities* (Baden-Fuller and Haefliger, 2013, p. 424). Baden-Fuller and Haefliger (2013) took note of the way that the business model frames managers, entrepreneurs, and developers hold in their heads determine the way in which technology gets developed. The connection between business model choice and technology is two-way and complex. On the other hand, technology will influence business model possibilities. Business models and technologies interact. In this research it is noticeable how the companies adopting the manufacturer-contractor prototypical business model, started to focus on the services, the food printing material, deciding to adopt a razor-and-blade type of value proposition, value delivery and value capture. Thus, it became important to develop the food material, the packaging of food material and compatibility with the food printer as well as find partners that could develop technology in this direction. That is a very different direction compared to the dominant manufacturer business model focusing on low-cost, easy-of-use, and home users.

Thus, the link between business model innovation and new technology is not a one-way street, first comes technology then comes the business model. This research implies it is better described as a two-way street, i.e., the business model and the technology interact, as suggested by Baden-Fuller and Haefliger (2013).

5.2. Facilitating diffusion of 3D food printing technology through business model innovation

The Future Meal project highlights the resistance or inertia to the diffusion of new technology which does not necessarily present in one of the parties involved. Instead, the resistance to diffusion could be the sum of the friction that exists in each party. One of the conclusions from the project was that 3DFP technology has too low an output speed to be used practically and the challenge of the unavailability of compatible printable food ingredients. In addition, the municipal kitchens might not have the capability required to operate the proposed technology in its current form.

The project involved three major stakeholders, i.e., the printer manufacturer, the food supplier, and the municipal kitchen. Looking at it superficially, the project seemed to point to the need for a technical solution, one which has a high output speed, is capable of printing with existing food ingredients, and is also easy to operate. Since this was an entirely new market for the technology manufacturer, there was little incentive for investing in product redesign and improvement, not to mention that the technical solutions are neither readily nor easily available. For example, extrusion-based AM technology is known to be a relatively slow process. With the consistency of puree-liked food materials investigated in the project, the deposition speed is converse to the precision of the deposition (Derossi *et al.*, 2020). The development of new and safe-for-consumption 3DFP-compatible printing materials also takes time.

In a stalemate like this, a look into the business model could circumvent the need for immediate technical development. Paper 2 offers a number of examples of business model innovation that could be used to break the inertia. These business models could be used temporarily to overcome the initial resistance, while the technology gets developed, with the aim to change to a more desirable business model at a later stage. The author is aware of the difficulties and challenges presented in every attempt to do a business model change. First of all, the firms might not be aware of the possibility to change their business model at all. The thought of what business model to use is linked to the cognition and capability of managers running the organization (Tripsas and Gavetti, 2017), and there can be a lot of inertia when it comes to changes in the business model.

Regardless of the difficulty and resistance to the business model change, a new business model is likely to result in a new set of requirements imposed upon the business model components. In this example from the Future Meal project, the choices of business model dictate where the 3D food printer would be located, who would operate it, and how the maintenance would be done, see figure 2.

With the leasing business model in which the technology manufacturer leases the 3D printer to the municipal kitchen (A) or at the elderly care center (B), this would require that the improvement focuses on ease of use and output speed. The requirement in terms of space for the printer, the price, and staff training would be comparable to a piece of kitchen appliance already used in place. The 3D food printer sitting at the elderly care center would likely be smaller and easier to operate by the care staff.

With the business models that the manufacturers become service providers for 3D-printed food (options C and D), there would be a possibility to increase the size and the number of 3D food printers to compensate for the slow speed of an individual printer. However, this change would entail the need for an entirely new set of capabilities for the manufacturers.

In option E, a third part was added to the setting to operate the 3D food printers and distribute the 3D-printed food to the municipalities. The third party would be the one who possesses capabilities unfamiliar to the other parties, thus reducing the inertia. The development of the 3D food printers would focus on reliability to keep the printer running as long as possible before there is a need for maintenance as it would affect the operating cost. Keeping the operating cost low is just one of the concerns for option E. The economic return would need to be enough to attract the interest of the service provider to enter the market.

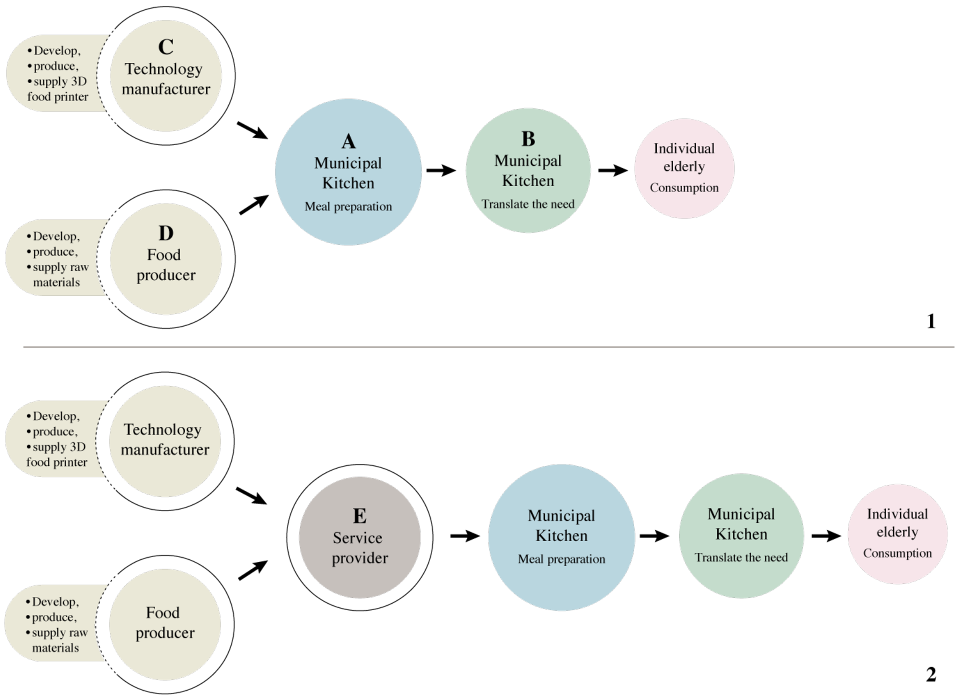

Figure 3. Proposed relationships between actor-networks in Future Meal (1: as it was anticipated during the project, 2: with the introduction of a service provider)

The discussion so far has emphasized the relationships between business models and product development. This research supports the notion that the choice of business model exists in the cognition of the managers before product development even starts (e.g., Åkesson *et al.*, 2021). When the resulting product does not meet the expectations of either the organization or its customers, there is always a choice to be made whether to modify the product and/or the business model.

As observed in prior research business model innovation often challenges the current resources and capabilities as well as organizational processes and leadership in the company (Teece, 2010). The business model innovation process has been described as going through a number of stages such as initiation, ideation, integration and implementation (Frankenberger *et al.*, 2013). Clearly the Future Meal project, from a business model perspective, is in the initiation phase, which includes a preliminary assessment of the new technology, the environment, searching for needs and business opportunities (cf. Frankenberger *et al.*, 2013). The assessment identified some shortcomings of the 3DFP technology such as slow output speed and the shortage of compatible food materials as well as lacking capabilities of the hospital kitchens to operate the equipment. However, a need, elderly suffering from dysphagia, was identified and costs for the hospitalization of undernourished elderly persons were estimated. The printed prototype timbales proved that the technology could produce the intended results as well as first user responses (elderly, relatives, and nurses). These are normal activities in the initiation phase trying to assess the possibilities for a business case of a new technology.

Prior business model innovation research has generally stressed the importance of experimentation and learning (e.g., Sosna *et al.*, 2010) and it has been described also as an empirical pattern in the 3DFP industry (Flammini, 2017). The experiment with business model components, testing components of value propositions, value creation value delivery, value communication, and value capture, as a way to identify a viable business model is advocated by (Blank, 2013) in the lean start-up method. Another method to facilitate business model innovation is to use prototypical business model innovation patterns (e.g., Osterwalder and Pigneur, 2010; Gassmann *et al.*, 2014) and to conduct workshops with relevant stakeholders in order to create ideas for a viable business model i.e., to proceed from initiation to ideation in the business model innovation process. Using the identified prototypical business model patterns in paper 1, three prototypical business models (modified manufacturer business model, leasing business model and third-party service provider business model) were constructed in paper 2 and proposed as possible business models for the commercialization of 3DFP technology in elderly care. While workshops with the relevant stakeholders, timbale producers, 3D printer manufacturers, municipalities, central kitchens and nursing homes, never took place within the Future Meal project this would be the next natural step in creating a viable business model.

5.3. Contributions and future research

Empirical research on business and economic aspects of AM in general (Holzmann *et al.*, 2019) and 3DFP technology, in particular, (Flammini, 2017; Flammini *et al.*, 2017) is still limited. This research contributes to the field of business models by complementing empirical studies of business model innovation in the context of novel technology, i.e., 3DFP technology. In line with prior research (e.g., Chesbrough, 2010; Holzmann *et al.*, 2019; Flammini, 2017; Flammini *et al.*, 2017), the empirical results show that there is a clear link between business models and technology. The results show that the same new technology can be commercialized through different business models affecting the direction and speed of diffusion of the new technology (Chesbrough, 2010). Moreover, this research complements and extends prior research on AM business model patterns (Holzmann *et al.*, 2019) and 3DFP business model patterns (Jia *et al.*, 2016; Flammini, 2017; Flammini *et al.*, 2017) by presenting and analyzing the current business models that 3DFP companies apply to commercialize the technology. The two dominating business model patterns of 3DFP, manufacturer and manufacturer-contractor, identified in this research, verify the similar two patterns identified by Flammini (2017).

Furthermore, this research contributes to business model research in general. As for studies of business model innovation in AM and 3DFP, empirical studies are limited, especially quantitative and mixed-methods studies (Wirtz *et al.*, 2016; Holzmann *et al.*, 2019). Generally, empirical research on business model innovation relies on qualitative studies of a single or a few case studies. Thus, there are limited possibilities for generalizations (Zott and Amit, 2007). This study is a mixed-methods study combining a survey of 24 3DFP companies' business models, following an original approach to measure and statistically analyze business models pioneered by Abdelkafi *et al.* (2013), in combination with qualitative data in the survey as well as a case study of 3DFP development project. The componential approach in paper 1 opens up for generalizations as well as comparisons with business model innovation in other industries.

5.4. Implications for further research and managerial practice

The componential approach used in paper 1, measuring and analyzing business model patterns, pioneered by Abdelkafi *et al.* (2013), may be applied to the study of business models and business model innovation in any industry or any type of context. Thus, comparisons of business models in use between industries, and generalizations regarding business model patterns in industries and other contexts might be possible to move the research field of business models beyond its dominance of case studies (Foss and Saebi, 2017).

Further research can focus on the process of business model innovation. The lean startup method has been mentioned (Blank, 2013) but this is applicable to startups. To experiment with, design, test and evaluate, innovation processes for established companies, introducing early integration of tools and methods for business model innovation, would be interesting. Methods that facilitate and integrate business model innovation (design, prototyping, and testing) and the product being developed in the company's innovation processes are still lacking (Munir *et al.*, 2022).

There are several implications for management and entrepreneurs aiming to change a current business model or to design a new business model. Business model patterns in an industry might serve as blueprints for new entrants or existing companies. Replication of proven and functioning business models may reduce risk and development time, but limits innovativeness. Thus, business model patterns may also serve as starting points to innovate the business model in new directions, deviating from competition. This might require acquiring or partnering with other companies complementing with new capabilities and competencies. For example, personalized nutrition still seemed to be an unexploited value proposition in 3DFP. Organizing workshops and experimental development with companies having capabilities in 3DFP, food materials and nutrition could be a way to create, design, test and evaluate such a new business model.

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