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The influence of business model on the development of 3D food printing technology for dysphagia patients in elderly care

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ABSTRACT

Dysphagia, or difficulty swallowing, affects 10–30 % of persons above 65 years old. Texture-modified, easy-to-swallow, puree-like food in the form of timbales is usually served to this group of patients. Due to the characteristics of timbale, its appearance only remotely reminds of the original ingredients, leading to reduced appetite, reduced nutrition intake, and even malnutrition. 3D food printing of timbales can potentially preserve dysphagia patients' quality of life and prevent undernourishment by producing more realistic and aesthetically pleasing food. 3D food printing of timbales is however challenging: creation and industrialization of food formulations adapted to the 3D food printing process; speed, hygiene, and reliability of the 3D food printers, etc. In a research project in the context of Swedish elderly care, both technological and economical aspects were investigated. This paper uncovers that the business model dominating the 3D food printing industry is not suitable for this particular market segment. This paper presents several business model alternatives and shows that the choice of the business model will influence and guide the further technological development of timbale printing. The paper also outlines to which extent these findings can be applied to other countries and to similar markets where AM has not taken off or has not been widely adopted.

1. Introduction

Dysphagia, or difficulty swallowing [1], is caused by motoric dysfunction (mainly neuromuscular disorders) or narrowing of the esophagus, resulting in disturbance in the transport of food to the stomach [2]. Dysphagia can be temporary or, as this is the case for many elderly, permanent. Dysphagia affects about 8 % of the world population, or 590 million persons [3], 10–30 % of persons above 65 years old [4]. Dysphagia patients need special food, called timbales, with a consistency adapted to difficulty swallowing. However, texture-modified food in the form of timbales are mainly purées and thickened liquids with an appearance that in most cases only remotely reminds of the original ingredients. Not only is the appearance of this food less appetizing, but it also reminds constantly the patients of their conditions, and, as food intake is a social interaction in many societies, this special food treatment tends to lead to isolation [5]. Moreover, patients suffering from neurogenerative diseases, such as Alzheimer's, may refuse to eat food they do not recognize. These and other factors lead often to undernourishment, a state from which elderly patients seldom recover. It was estimated that dysphagia cost US healthcare over USD1 billion annually [6] by 2008. Dysphagia is also a health concern with large health, social and economic impacts.

3D food printing of timbales can potentially preserve dysphagia patients' quality of life and prevent undernourishment by producing realistic and aesthetically pleasing food. 3D food printing brings also the opportunity for meal customization, including individualized integration of dietary supplements. There are several technical challenges associated with the 3D printing of timbales, such as the design of the input material, hygiene, speed, reliability, etc., but there are also economic challenges associated with it, which might both hinder and govern the development of the technology. While correct diet is very important for health preservation, the food budget in nursing homes and similar institutions is severely restrained and it makes it difficult to invest significantly in this high-risk high-cost technology.

In a research project in the context of Swedish elderly care, both technological and economical aspects were investigated. This paper presents the findings from the project that the business

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model dominating the 3D food printing industry is not suitable for 3D printing of timbales. 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 3D food printing technology. The link between business model and technological development is highlighted in other industries where additive manufacturing (AM) has not taken off or has not been widely adopted yet.

This paper is organized as follows. The next section is dedicated to 3D food printing of timbales and business model. Section 3 presents the research project and highlights the issues for further technological development. Section 4 presents scenarios with alternative business models in the frame of the 3D food printing of the timbales market which could enable the further development of the technology. Finally, the implication for the development of AM technology in the current market for not yet penetrated industries is discussed.

2. Theory

2.1. 3D food printing of timbales

While there is research on treatments for dysphagia and there are training and rehabilitation programs for improving swallowing function, timbales (that is, mainly purées and thickened liquids) "have become a cornerstone of dysphagia management" [3, p. 280]. Timbales are produced by reducing food particle sizes and adding ingredients such as soy proteins, gelatines, and sauces, to liquefy, thicken or stabilize the food. It is possible to mold timbales, which gives an acceptable appearance to some food elements (e.g. sausages). It is also possible to manually shape them or use piping tips for decorative purposes (although in that case, it does not make the food realistic). The resulting timbales using some of those techniques are presented in Fig. 1. It is possible to manually shape timbales into very realistic food meals, see [7] for examples, but this requires training and is much more expensive than the other techniques. 3D printed timbales would allow for the possibility to have a relatively realistically good-looking food using less personal resources.

3D food printing present further potential advantages. The layer-by-layer technology allows for combinations of ingredients that are very difficult or impossible to realize with molding or by hand. It opens also for meal customization. Regarding appearance, the elderly of different generations would prefer different food based on their upbringing; with the increasing multi-cultural background of the institutionalized elderly, customization will be soon an important requirement. It is also possible to customize meals according to medical conditions, such as allergies or the need for dietary supplements.

Several technologies allow for 3D printing of food [8]. For liquid-based materials, inkjet printing and different extrusion processes are possible [9]. Extrusion can be performed in a support bath, relieving the need for support [10]. For powder-based food materials such as sugar, binder jetting, selective laser sintering (SLS), and similar processes are available [9]. In practice, the most used technology so far for timbale is extrusion. Powder-based processes require further treatment to give the food its intended structure, and extrusion with a support bath presents hygiene-related challenges (as of now).

3D printing of timbales presents however several general challenges. In general, AM has always suffered from its relatively low speed and reliability, and high cost. These issues become critical when dealing with food. Hygiene is another important aspect. Some of the most difficult challenges are: the creation of food formulations that can be adapted to the 3D food printing process (extrusion), given that food gels exhibit viscoelastic rheological behavior [11], that present similar taste and texture to the original ingredients or meal with an appropriate nutritional content; the scale-up and industrialization of these formulations; the many different parameters governing the printability of these special food elements; post-processing step (cooling, heating or re-heating food for example).

2.2. Business model and technology development

A business model can be understood as a mediating construct that connects technology development to economic value creation [12]. Arguably the two core functions of a business model are value creation and value capture [13]. The former describes how a firm performs activities to create products and services that generate value for every-one involved in the activities. How the firm creates economic return is described by the value capture. Chesbrough [13] emphasized the importance of the net created value which is what attracts suppliers, partners, and customers, while the captured economic value is necessary to the survival of the firm.

3. Research project description and findings

3.1. Project description

'Future Meals' was a two-year project investigating the possibility of using 3D printing technology to produce food for the elderly suffering from dysphagia. The project was multi-disciplinary, involving, on one side, researchers within food engineering, additive manufacturing, gerontology, dietetics, interaction design, sociology, and, on the other side, companies within additive manufacturing, timbale and meal production, as well as central kitchens and nursing homes in two municipalities of the South part of Sweden (the majority of nursing homes are subventioned by municipalities and meals delivered by central kitchens). The project involved a multi-sided exploration of the topic:

- Development of 3D-printable timbales for different kinds of food ingredients (broccoli, chicken, and bread) to assess technical feasibility and required development efforts;
- Exploration of printing methods that would allow the recreation of realistic-looking printed structures;
- Meal customization possibilities;
- Attitude towards the 3D printed food of people involved, including the elderly, the nurses who take care of them, and the relatives of the elderly;
- Analysis of suitable business models for this type of market, the results of which are presented in this paper.

3.2. Project's findings

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, see Fig. 2. In addition, the elderly participating in the user test did not have a negative response to food prepared by a 3D food printer. 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 revealed also many technical challenges to be overcome before the technology could put food on the table. Creating suitable timbale mixtures and scaling the production process is time-consuming. Adapting the printing processes for different timbales is also largely a trial-and-error process with many interactions required with the timbale creation process. The low

Fig. 1. Examples of timbales. Courtesy of the central kitchen of Helsingborg, Sweden.

Fig. 2. Examples of 3D printed timbales. Left: chicken leg and broccoli; right: cinnamon buns. Courtesy of RISE Research Institutes of Sweden.

deposition speed of extrusion technology was another cause of concern. Although the need for timbale meals for the dysphagic elderly represents just a small portion of the food prepared daily by the kitchen, the current 3D food printing technology is still too slow to replace the manual food preparation process. More technological development is needed but in order to proceed, a viable economical model is required. The study of suitable business models is presented in the next section.

4. Business model analysis

4.1. Adopted analysis approach

The approach taken for the analysis and proposal of business model alternatives in the considered specific market segment (3D food printing of timbales for elderly care) was the following. First, the business models adopted in the larger 3D food printing market were reviewed, using a business model framework based on the value-focused business model proposed by Abdelkafi et al. [14] and on business model patterns classification, e.g. [15,16] to find the so-called 'prototypical' business model (i.e. the most representative, hereafter called main business model) of the 3D food printing market. Then the business model literature was reviewed to identify similar contexts in which the implementation of business models led to successful and widespread adoption of new technology. Based on these findings, alternative business models for the current market could be proposed.

The analysis of the main business model of the 3D food printing industry is presented in Section 4.2, the main results from the business model literature are showed Section 4.3, and alternative business models for the current market are proposed in Section 4.4.

4.2. Analysis of the main business model of the 3D food printing industry

The business models that are typically implemented in the 3D food printing industry follow the *Manufacturer* type of business models, according to Malone et al. [15]'s taxonomy. The complete study can be found in [17]. In this classical business model, the manufacturer transforms the resources to manufacture products that are sold to the customer to generate revenue. Applying the same business model type to the context of timbale printing leads to the following scenario.

The 3D printer manufacturer would mainly supply central kitchens with 3D food printers, capable of printing with timbales. It could also provide service and maintenance. The central kitchen would use the capability to produce timbale meals for the nursing homes. Using relevant components of the Business Model Canvas [22], the 3D printer manufacturer has manufacturing capability as their key process, the 3D printers as their value proposition, the municipality elderly care as their customer segment, and the economic return for selling the product and service is the revenue stream. Similarly, the timbale producer who supplies the kitchen with 3D-printable timbales could be described by the same manufacturing business model. This business model served as the basis of understanding for the parties involved during the Future Meals project, see Fig. 3.

However, this business model proves problematic as it does not have the net value gained for all the parties. For one thing, most municipalities have limited demand for high-capacity 3D food printers because of a relatively small number of elderly that would need timbale meals from most central kitchens. They have also relatively limited space for equipment and would need a versatile 3D printer if different types of meals were to be prepared. For exam-

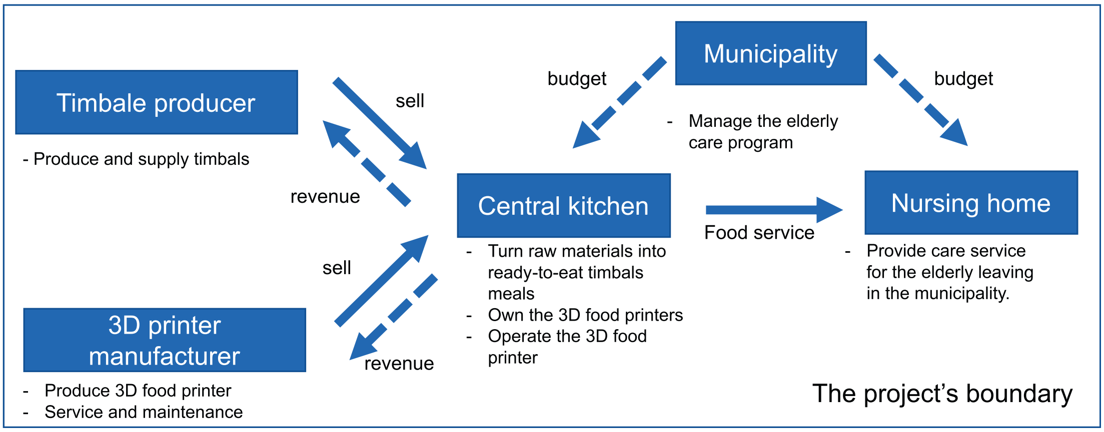

Fig. 3. Actor-network representation with the main business model of the 3D food printing industry as a basis.

ple, some timbale ingredients require high temperature for extrusion while others require cold temperature. Another aspect is both the limited quantity and large diversity of timbale ingredients that would be needed for each day. This limited demand and high requirements make it less attractive to the 3D food printer manufacturers and for timbale ingredient producers to develop specific technologies within this context. In short, under this business model, the existing technology does not have the performance to justify the investment by the municipality and the potential economic gain is not attractive to the manufacturer to continue the development.

4.3. Business model development in similar contexts

The literature highlights several possible paths for business model development in similar cases. Only the cases that are exploited in the next section are presented. One case where a change in the business model led to the commercial success of new technology was when Xerox introduce the leasing business model and pay-*per*-copy for its Model 914 copier [12]. The cost of acquisition for Xerox's model 914 copier would have otherwise deterred its customers [12]. Another case in which the implementation of a new business model led to widespread adoption of new technology is the case of the third-party ownership (TPO) for the solar panel market in California [18]. The TPO business model, itself a kind of leasing business model, also relocated the initial investment burden from the homeowner to the financial institutions. The homeowner benefited from the energy generated, while gradually covering the cost of the solar panel during the period of the contract. The implementation of the TPO business model effectively removed the need for down-payment which had been a barrier for many customers.

These business models are interesting once the technology is relatively mature. When the technology is still under development, several steps might be taken before business models can be adopted. One of them is to extend the boundary of the current context and involve other actors that might have an indirect interest in the successful development of the market segment. Such a strategy can be found in the third case of AM for the marine industry. This market presented a similar lock-up: one of the main advantages of AM for the marine industry is the possibility to get spare parts and part upgrades. But there were few incentives for ship owners and builders to invest in the technology if there was no worldwide availability, and little incentive for the AM manufacturers to develop, certify (a costly and lengthy process) and deploy the technology while the market was not secure. A decisive impulse came among others from the involvement of the certification agencies and port authorities in the development of the market [19]. Port authorities do not get direct benefits from the spare part markets but indirectly they will benefit from parts transitioning through their facilities, from the installation of manufacturers at their location, from the increased traffic, etc. The Maritime and Port Authority of Singapore, among others, aims at becoming an AM technology hub and has invested heavily in this segment [20]. AM in the marine industry is now catching up with other AM markets at a high pace.

The current context presents some similarities. In Sweden, the care of the elderly, including the provision of food services, is placed under the responsibility of the 290 municipalities, while hospitalizations are placed under the regional health care system. The hospitalization cost due to undernourishment of the elderly is large: no precise figures exist but potential savings if undernurhíshment was prevented is in the 10 s of USD million in Sweden alone [21, p. 8]. By involving regions in the development of the 3D printing of timbales, reducing the regions would indirectly benefit from its use.[1]

The next section presents how these alternatives could be implemented and their technological implications.

4.4. Business model alternatives

Under these alternatives, the regional health care systems can be involved and participate in technological development. Their interest would lie in being able to verify and quantify the health and cost benefits of 3D printed timbales. Three business model alternatives are proposed as a way to lower the barriers from both the technology developer and the user (see Fig. 4). It would be too speculative to discuss the involvement of regional health care systems once the technology is more mature, but the business models below hold independently of it.

4.4.1. A modified manufacturer business model

The first proposed alternative retains the features of a basic manufacturer business model. The key modification is for the 3D food printer manufacturer to change their customer segment from the municipality to the timbale producer. As an ingredient supplier, the timbale producer could use the 3D food printing capability in-house to produce 3D printed timbale as ingredients that are supplied to the municipalities. In this scenario, the timbale producer would absorb the cost of investment, not the municipality.

[1] Governmental support can of course be held for research purposes but not for the complete technical development of a product.

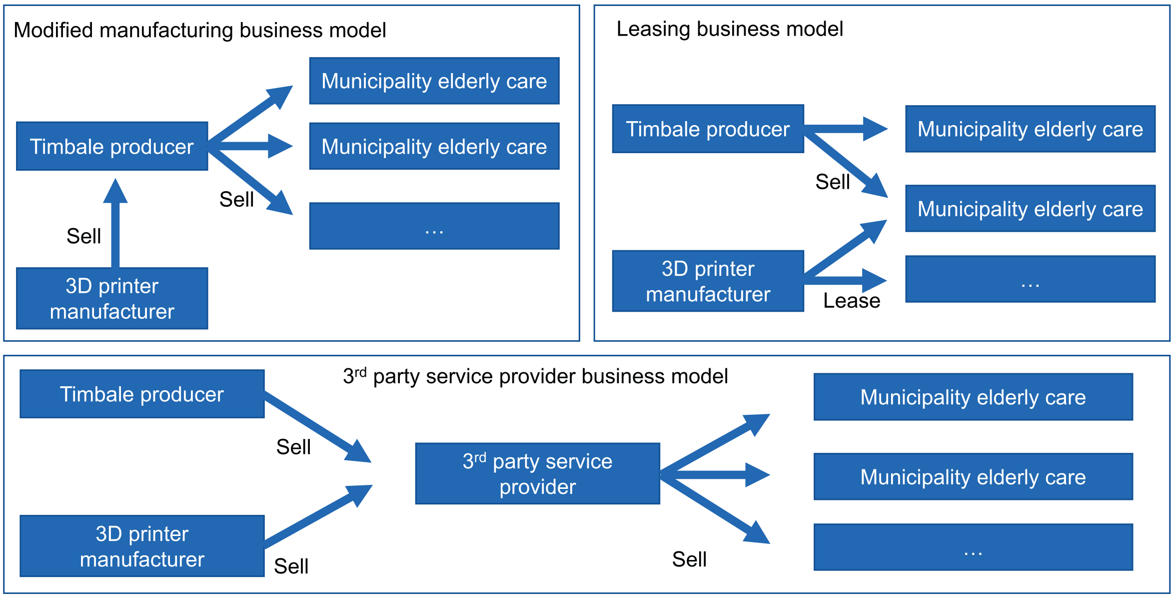

Fig. 4. The schematic of the three proposed business models.

As the timbale producer supplies their product to many municipalities, the poll of potential demand for 3D printed timbales is larger.

The technical implication of this business model is the approach to the development of 3D food printers that are locked-in to the print material i.e. the timbales in this case. By owning and operating the 3D food printer, the timbale producer has also a prospect of partnering with the 3D food printer manufacturer and customizing the machine to their timbales recipe. Moreover, a combination of industrial-scale and desktop 3D food printers could offer an even more flexible solution. While the large industrial machines are used by the timbale producer, the less sophisticated desktop printer can be located in the municipality kitchen for simpler tasks.

4.4.2. Leasing business model

The leasing business model can be used by the 3D food printer manufacturer as an alternative to the selling business model. In this business model, the kitchen operates but does not own the 3D printer for the duration of the contract. The immediate benefit to the kitchen is the reduced cost of acquisition. It also comes with a reduced risk to the kitchen in that it is not bound to the investment and can move to a newer technology once it becomes available. The 3D food printer owner takes some risks and has to find ways to recover the residual value of the leased product after the contract is over. Regarding the technical aspects, this would naturally lead to higher quality and reliability of the printers (compare home paper printers to the professional leased printers).

There are also alternatives as to who would be the owner and lessor of the 3D food printer. Having the technology manufacturer as a lessor has the benefit that they retain the ownership of the product. This has several technological implications: the technology manufacturer as a lessor would have an incentive to develop the 3D printer in a way that values can be recovered from it at the end of the lease contract. It could be that the printer is modular, making it possible to upgrade certain modules with new technology, or it can be remanufactured into a new model.

Another option is to have the timbale producer as a lessee which is similar to what is described in Section 4.4.1, but the 3D food printer manufacturer would still retain the ownership of the printers. The technical consequence would be that the manufacturer, as a lessor, would have more incentive to improve the quality of the product to be attractive to the lessee.

4.4.3. Third-party service provider business model

In the previously presented business model, the 3D food printers were located in and operated by either the timbale producer or the municipality's central kitchen. Another option is to have a third-party operating the 3D printers and supplying the 3D printed timbale meals to the kitchen or directly to the nursing home. This service provider can operate at a regional level, providing 3D printed timbale meals to multiple municipalities and expanding the demand base. The collective increased volume of demands for timbale meals enables the service provider to invest in higher capacity technology, using different 3D printing technologies, and can operate multiple machines in one location.

As far as the production of timbale meals is concerned, the kitchen's key process would change from being a 3D printer operator to a demand coordinator, collecting and processing the needs for timbale meals from multiple nursing homes and passing them to the service provider. The timbale producer would supply the printable timbale ingredients to the service provider at centralized locations, not to the individual kitchens in multiple locations.

The centralization also has specific technological implications. Different types of 3D food printers can be used, which would mean that specialized, more effective, and robust printers could be developed, instead of a multi-function machine. The centralization has also an effect on the pooling of trained personnel. Instead of dispersing small and simple 3D food printers to be operated by staff at the kitchens, the service center can have staff specializing in different types of 3D food printers. This simplifies the technical development of such machines because more of the burden of process control can be put on the operators.

5. Discussion and conclusion

The implication of more actors in this context, such as regional health care, is essential to converge to viable business models and their related technology development. The different choices made by the actors of the market will influence significantly the way the 3D food printing technology for timbale will go. In the long run, however, these three proposed business models do not necessarily have to be used on their own, but can be used in combination, complementing one another. For example, small 3D food printers with specific, limited capabilities can be developed and used with selling or leasing business models in the kitchen, while the service provider business model provides more specialized services at the regional level.

Dysphagia is a global health concern and, with provision for some elements specific to the Swedish context, the presented results can easily be extended to most countries where elderly care is decentralized.

While in some industries, technological advances drive the development of the market, 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 Meals project is not unique to the 3D food printing technology. It is a situation where a new and promising technology does not fit well into the main business model of a market. For the problem to attract the industry to work out the technical solutions, there has to be an attractive business opportunity. We have mentioned earlier two examples of the Californian solar panel industry [18] and Xerox's model 914 copier [12]. In both examples, the technological challenges have been overcome and the resulting products were able to fulfill their intended function. Similarly, the marine industry is working on lowering technological barriers by considering the industry as a whole [19,20]. In several other fields where AM has not taken off yet, as in some parts of the health care industry, for example, technology development should go hand in hand with business model development.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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