Aalto University
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A quantitative study

Matti Lötjönen

International Business
Bachelor's Thesis
Supervisor: Susan Grinsted
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ABSTRACT OF
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Objectives

The main objectives of this study were to find and measure the factors affecting how consumers intend to utilise additive manufacturing and to analyse how consumers can be involved in additive manufacturing activities with businesses, keeping in mind the opportunities and weaknesses of the technology.

Summary

Opportunities and weaknesses of additive manufacturing as well as opportunities for user involvement were examined in light of existing literature, while a quantitative survey was used to measure the factors that influence consumer 3D (three-dimensional) printing adoption.

Conclusions

The research showed 3D printing use of consumers is positively influenced by the technology having benefits for consumers, easy-to-use products and support being available, and 3D printing products having a good value. Consequently, these factors help consumers to co-create or co-design products with companies or utilise 3D printing in entrepreneurial capacity.

Key words: additive manufacturing, 3D printing, user involvement, consumers, co-creation

Language: English

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ABSTRACT

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1. INTRODUCTION

1.1 Background

3D (three-dimensional) printing is a method of manufacturing that produces objects based on three-dimensional models, called CAD (computer aided design) files. From its initial use mostly in prototyping, 3D printing has evolved to be used by companies and consumers alike. For example, Boeing has already used 3D printed parts in its aircrafts (Flores et al., 2017), while consumer 3D printers cost as little as $400 (Matias & Rao, 2015). The low cost of 3D printers has opened possibilities for consumers to adopt the technology.

3D printing enables consumers to co-create products with companies. Consumers may participate in designing products with the firm using 3D modelling software. The 3D model allows consumers to see a prototype of a product before any physical manufacturing. Alternatively, consumers may print 3D models provided by companies or other consumers with their own printers, thus participating in the manufacturing process. In some cases, consumers may even become entrepreneurs by utilising the 3D printing technology for financial purposes.

The topic is important for international business, as online sharing of CAD files globally and printing them locally provides a new way of doing business internationally. Some functions executed by companies may be transferred to consumers, challenging the traditional role of consumers as buyers. Understanding the opportunities and the weaknesses of 3D printing allows companies to implement the technology for products and processes where it can be used most effectively, for example when producing highly customised products.

1.2 Research Problem

Although 3D printing has current applications and allows new opportunities for consumers to be involved in the production cycle, users may face significant obstacles. Despite an increasing demand for locally customized products, 3D printing requires knowledge to operate efficiently as well as an initial investment to buy the technology, such as a printer. Few studies explore the topic of additive manufacturing from a consumer point of view, with most of that research focusing on qualitative methods. Thus, there is a research gap in approaching the topic of user involvement within additive manufacturing from a quantitative point of view.

1.3 Research Questions

This research aims to answer the following research questions:

1. What are the conditions and skills required for co-creation in 3D printing?
2. In which roles could consumers be involved with 3D printing?
3. What type of new entities could emerge in business models that integrate additive manufacturing?

1.4 Research Objectives

The objectives of this research are to:

- Find and measure factors affecting consumer 3D printing use
- Analyse the opportunities and weaknesses of 3D printing
- Define implications for consumers using 3D printing
- Explore business models in which consumers can adopt 3D printing

2. LITERATURE REVIEW

2.1 Introduction

Most commonly additive manufacturing is known as 3D printing, but some researchers also use terms such as rapid prototyping (Beyer, 2014), direct manufacturing (Khajavi et al., 2014), and home fabrication (Wade et al., 2017). Although some argue additive manufacturing is the official technical term (Hartmann & Vanpoucke, 2017, Steenhuis & Pretorius, 2016), for purposes of this study they are used interchangeably. The term additive is used to describe the technology because objects are built layer-by-layer (Berman, 2012), as opposed to traditional subtractive manufacturing (Beyer, 2014).

Additive manufacturing has been used since the 1980s, although being initially limited to making prototypes (Weller et al., 2015). 3D printing started to gain more widespread adoption only in 2005 with the start of the RepRap project, an open source community aiming to popularize the technology (Matias & Rao, 2015, Steenhuis & Pretorius 2016). Since the project's invention of MakerBot, the first assembled 3D printer for consumers in 2009 (Matias & Rao, 2015), the 3D printing market has grown sizeably and is still expected to grow rapidly (Hartmann & Vanpoucke, 2017). Yet, despite its technological advantages, additive manufacturing also has multiple disadvantages and uncertainties, which may limit its applicability (Berman, 2012).

To fully understand the opportunities and limitations of additive manufacturing, both aspects are first explored by analysing the existing literature. Then, the role of consumers and users in 3D printing are investigated, followed by discussion of the impact and connection of 3D printing on existing business models for both companies and users. Finally, a conceptual framework to illustrate factors affecting consumer acceptance and use of the technology is presented.

2.2 Benefits of Additive Manufacturing

The benefits or opportunities of additive manufacturing are widely discussed in literature. Generally, the literature agrees on the opportunities of 3D printing: increased levels of product customization, possibilities to manufacture more complex products, more sustainable manufacturing via lower material waste, and manufacturing of products using fewer steps (e.g. Berman, 2012; Weller et al., 2015). However, Weller et al. (2015) also argue that currently the applications of 3D printing are limited in terms of their scale, limiting its opportunities to niche markets. Rayna & Striukova (2016) see the restricted applicability as a benefit, however, as even small niches can be catered to.

Opportunities of 3D printing in supply chains are also discussed in several studies. Mohr and Khan (2015) see possibilities in 3D printing applications within limited physical spaces, consequently advancing supply chain decentralisation and localised manufacturing. Furthermore, they continue that supply chains can be simplified through online file transfers, compared to physical transportation of goods. Piller et al. (2015) agree with this idea and argue that the emergence of 3D printing will decrease the benefits of economies of scale. They defend their view by suggesting that by having products that better fit consumer needs can exceed the advantage of decreased production expenses via economies of scale. However, they are also critical in their view by accentuating that traditional economies of scale have been difficult to dissolve.

Some papers also consider 3D printing as an enabler for faster product development. Beyer (2014) sees a general movement towards shorter product life cycles, which can be achieved for example through accelerated learning and decision-making processes within product development. By studying additive manufacturing in apparel production, Perry (2017) found convenience to produce prototypes and fast production speed as main advantages of 3D printing, thus confirming Beyer's (2014) arguments. A paper by Royal Academy (2013) further combines faster production with shorter supply chains by considering both faster lead times and simplified supply chains as benefits of additive manufacturing. Furthermore, Bogers et al. (2013) argue that by having a more rapid product development, manufacturers can better react to market changes and consequently better supply real demand, while also having generally lower inventory levels.

To compare the benefits of additive manufacturing to similar technologies, 3D printing is compared to several technologies in literature. Ratto and Ree (2012) see 3D printer development similar to traditional 2D printers, in the way of 3D printers eventually penetrating daily life. Comparing industrial adoption to home adoption, Steenhuis and Pretorius (2016) find connection with mainframe and home computers, which were divided in their performance as current 3D printers. Wade et al. (2017) share this view by connecting home users of 3D printers with early computer tinkerers. Through this association, Ratto and Ree (2012) see 3D printing not only as a tool but as a larger development within social sciences and culture by introducing new ways of community exchange and combinations of work and design. Khajavi et al. (2014) add to the realism of this vision by indicating that 3D printing has followed the Moore’s law in terms of technological development and more powerful machines being developed each year. Chen (2016) go even as far as proposing that additive manufacturing will assist in a third industrial revolution; yet, this argument is not supported in other literature.

Adoption of 3D printing in manufacturing can also bring cost savings. Beyer (2014) investigates cost savings from the perspective of reduced product weight, leading to subsequent energy savings. Bogers et al. (2016) add that by having machines capable of producing very differentiated products, sunk costs invested into manufacturing facilities can be reduced. Similarly, Flores et al. (2017) continue that invested capital can be reduced not only from machines but also on inventories due to additive manufacturing’s capabilities of build-to-order production. Ford and Despeisse (2016) further integrate the views of Beyer (2014) and Perry (2017) of reduced production time with cost savings. Finally, Kietzmann et al. (2015) conclude that in addition to argument by Flores et al. (2017) on inventory savings, production closer to consumers also reduces transportation costs, thus potentially leading to a larger environmental benefit of reduced pollution.

2.3 Disadvantages of Additive Manufacturing

As a disadvantage of additive manufacturing, Chen (2016) proposes that global trade will decrease. The argument is supported by a global supply chain simulation with findings of reduced transport volumes and production moving closer to customers. Despite the simulation’s limitations of considering only four imaginary countries, Chen expects a major transformation of global logistics. However, Weller et al. (2015) argue that existing economies of scale continue to stay more cost-effective over 3D printing in markets that are substantial in their size and have low product differentiation. Continuing, Weller et al. define four market attributes that would make additive manufacturing advantageous: complex products, small-scale production, strong appeal for customisation and geographically remote demand for products. However, Mohr and Khan (2015) point out that although localised production can lower logistics costs and offer more flexibility in supply chains, lacking economies of scale may increase production costs. Therefore, they emphasize the significance of being aware of the limitations and knowing the appropriate applications of the technology.

Questions of legal matters and intellectual property are also associated with additive manufacturing. Bogers et al. (2016) considers concerns of liability to surface as parts and products are not manufactured according to original processes nor approved by the manufacturer. Adding to this, Flores et al (2017) argue that better intellectual protection needs to be in place for effective supply chains build on distributed manufacturing. Jiang et al. (2017) adds that issues regarding quality assessment and product warranty needs to be addressed for 3D printer products, thus considering intellectual property breaches as significant threats for manufacturers. Highlighting potentially negative consequences, Kietzmann et al. (2015) name 3D printing of medicines and vaccines as exceptionally frightening due to their need of high quality assurance standards. They furthermore find similarities between the copyright issues of digital music and films and 3D printing products and models required for them. A paper by Royal Academy (2013) mentions 3D printers being capable of manufacturing illegal or restricted products, going even beyond the concerns outlined by Kietzmann et al. (2015).

Another major issue with 3D printing discussed in literature are the skill and knowledge required to utilise the technology (Flores et al., 2017). Ford and Despeisse (2016) agree with this, stating that learning the requirements demand a longer period of time and suggest governments to implement educational programmes to drive this development. Halassi et al. (2018) further elaborate that education needs to be aimed at the general population, even to children, as a snowball effect can accelerate the learning of 3D printing. Ratto and Ree (2012) add that despite numerous 3D modelling software options, it is the difficulty in learning to use them that restricts the overall population to use additive manufacturing effectively. Steenhuis and Pretorius (2016: 1006) well illustrate the issue by arguing how 3D printing is far from “push of the button” technology to be able to produce consistent results for consumers. Wade et al. (2017) summarise the problems faced by users by showcasing how even after learning the use of a CAD design software, the level of details involved in transferring the model into a physical product is demanding for consumers to fully grasp.

Additive manufacturing also faces multiple technical obstacles. Most issues described in literature concern the high cost of production and the low durability of 3D printed items (e.g. Berman, 2012; Chen, 2016, Flores et al., 2017). In particular, Chen (2016) highlights the steep cost of materials used in printing while Ford and Despeisse (2016) emphasize more the fixed machine cost yet expecting a price decrease upon more widespread technological adoption. As for even more technological issues, Piller et al. (2015) point out how current materials used for printing do not necessarily meet the standards of traditional processes, thus limiting the applicability. A paper by Royal Academy (2013) further notes that a demand for higher quality materials exists. However, Rayna and Striukova (2016) also illustrate how 3D printers can be limited in the number of materials that they can use, thus arguing how the issue of materials is not related only to the materials per se. Finally, Ford and Despeisse (2016) criticize current 3D printers of lacking automation and consequently requiring significant post-processing, therefore questioning the commonly agreed benefit of reduced material waste in the manufacturing process.

2.4 User Involvement

Another topic often analysed in the literature is the role of users and consumers in being involved in 3D printing activities. Piller et al. (2015) claim that 3D printing facilitates users to become producers or entrepreneurs, using a concept of makers to describe them. They also describe how previously consumers were not able to transform their innovations to finished products, leaving no choice than to sell the designs to commercial producers. Yet, Piller et al. state that by adopting 3D printing, the issue may not persist due to concepts of user manufacturing and user entrepreneurship. The latter has been defined by Shah and Tripsas (2007: 124) as the “commercialization of a new product and/or service by an individual or group of individuals who are also innovative users of that product and/or service”. The definition is agreed by Holzmann et al. (2017) by identifying two attributes of businesses with user entrepreneurship: flexibility and low capital investments. These characteristics are shared by Piller et al. (2015), due to additive manufacturing providing flexible manufacturing without the requirement of additional tools or moulds. Furthermore, four industrial characteristics that promote user entrepreneurship are defined by Shah and Tripsas (2007): combining enjoyment with financial benefits, low opportunity costs, markets with high, niche demand and innovative products with ambiguous usage. Surprisingly, while neither is discussed by Piller et al. (2015) nor Holzmann et al. (2017), Rayna and Striukova (2016) point out that 3D printing truly allows catering to any niche market despite its size. They further elaborate their views with a comparison of optimal production quantities of additive and traditional manufacturing: the former allows optimization even as small samples as 10 units while the latter is supreme for batches over 10,000 units.

Adding to the discussion about role of consumers, Holzmann et al. (2017) claim that opportunities in entrepreneurship do not exist only in manufacturing but also in 3D model design and sharing and offering 3D printing services. The latter enables users to rent out printing services to other users, which makes it perhaps the most interesting. This claim is supported by Piller et al. (2015), as they predict that facilities called fablabs, which provide local printing services, will emerge. A more recent study by Pauceanu and Dempere (2018), however, argues the number of fablabs has already increased rapidly, with nearly 1,300 fablabs currently established in 30 countries. Holzmann et al. (2017) proceed the discussion by proposing four combinations of business models with user entrepreneurship based on two measures: potential number of customers and the cost to exploit opportunities. Yet, it is noteworthy that their research on existing user entrepreneurs, using a sample of eight companies, found no current utilisation of fablabs by the entrepreneurs. Although the small sample size might restrict making generalisations, Holzmann et al. present two reasons for companies not to use fablabs: significant initial costs and growing legal problems, thus potentially contradicting the claims by Piller et al. (2015). Yet, Pauceanu and Dempere (2018) identify fablabs to bring benefits for entrepreneurs by offering support in product development, leading further to economic progress.

Yet, the issue of user involvement has also been approached from a different perspective. Jiang et al. (2017) have conducted a Delphi survey on the opinions of both academic and industry experts. According to the findings of the survey, academic experts do not see users buying private 3D printers but that instead they would use them at nearby fablabs or similar local and shared facilities. Ultimately, this challenges the vision of Rayna and Striukova (2016) of this stage of local manufacturing being only a step towards the final form of home fabrication. Yet, Jiang et al. (2017) describe that statements were perceived differently by academic experts compared to industry experts. Berman (2012) concurs with Rayna and Striukova (2016) on their prediction of widespread 3D printing at homes as the prices drop. However, he also argues that the scenarios outlined by Rayna and Striukova (2016) and Jiang et al. (2017) may also exist at the same time if companies invest in shared 3D printers to lower costs of investments. Weller et al. (2015) have further concerns about the future of additive manufacturing by questioning whether intellectual property could inhibit user innovation. Rayna and Striukova (2016) also discuss the commission that online printing platforms collect as a potential effect diminishing the attractiveness of user entrepreneurship.

User involvement within additive manufacturing does not necessarily require users to become entrepreneurs but simply co-designers or co-creators. Wade et al. (2017) argue that even currently users have moved from being pure consumers to become ‘prosumers’. The concept of prosumers was already defined in the 1980s, referring to the role of consumers becoming producers (Bogers et al., 2016) for their own consumption (Halassi et al., 2018). Bogers et al. (2016) further continue that the creative design part can be executed solely by consumers or by design communities consisting of similar users, creating not only value for the consumers but also providing consumer data to manufacturers. Hermans (2013) has explored the concept of co-creation from the perspective of laymen who lack the skills and knowledge that professional designers have but who can finish the incomplete objects or drafts that the professional designers produce. Other alternatives that Kietzmann et al. (2015) suggest for co-creation are online services which allow uploading of 3D designs or other services which help finding locals with 3D printers to be used for a fee; therefore, not restricting co-creation to only co-designing but also allowing co-manufacturing. Going even further, Ratto and Ree (2012) consider co-creation as a form of civic engagement, comparing it to voting or protesting. However, Rayna & Striukova (2014) point out that despite enormous potential of co-creation, there are also challenges regarding copyright and incentive of users to be engaged. Weller et al. (2015) agree with this view by questioning in particular the consumer willingness for co-design, for example due to the fees charged by online platforms (Rayna & Striukova, 2016), high degree of design skills required (Wade et al., 2017) and the relatively high cost of consumer 3D printers (Matias & Rao, 2015). This critical approach challenges the views of some industry experts that predict home 3D printing to be present in all homes within 5 to 10 years (Kietzmann et al., 2015). In an attempt to find methods to increase consumer adoption of additive manufacturing and to induce co-creation, Matias and Rao (2015) suggest 3D printing companies to educate and inform consumers of the value of the technology, and in particular focusing on the easiness of product usage.

2.5 Business Models

Following the previous discussion about the role of users in additive manufacturing processes, the connection of user involvement and business models has also been analysed in the literature. Steenhuis and Pretorius (2016) compare the cost competitiveness of traditional manufacturers and consumers with 3D printers and find the latter more efficient due to lower labour costs. As a result, they predict consumers to start printing out more household items instead of purchasing them at retail stores, which may challenge current brick and mortar retailing. Shah and Tripsas (2007) argue that after developing such a product for solely personal use, a user can gradually shift towards entrepreneurship after recognising the underlying commercial opportunities. A more recent study by Hartmann and Vanpoucke (2017) still agrees with this vision, stating that 3D printing offers possibilities for new business models where the social impact and the role of communities are emphasized. Bogers et al. (2016) further confirm the statement and predict a reshaping of existing business models with a shift from manufacturer-centricity to consumer-centricity when additive manufacturing technologies are commonly adopted. Adding to the discussion, Jiang et al. (2017) consider the capability of companies to introduce new business models to help survive some challenges, such as those related to intellectual property rights.

The concepts of crowdsourcing or crowdfunding are also prevalent in discussions about 3D printing's business capabilities for users. Rayna and Striukova (2014) highlight that crowdfunding is a popular form of co-creation and that for some firms, their business models are built on co-creation activities. In their later study, Rayna and Striukova (2016) argue that additive manufacturing has helped crowdsourcing move from sourcing purely ideas to sourcing the whole production. Despite lack of consensus on the definition of crowdsourcing, Estellés-Arolas and González-Ladrón-de-Guevara (2012) define it as an online activity where a crowdsourcer, such as an individual or a firm, proposes to a crowd of users to carry out a task, such as developing an idea or a product, for mutual benefit. This complements the idea by Ratto and Ree (2012) who predict homes to be transformed into small factories, helping consumers to become the user entrepreneurs as defined by Shah and Tripsas (2007). Finally, Ford and Despeisse (2016) consider those with excess printing capacity to be the ones most likely to provide 3D printing services for other users, possibly in the form of crowdsourcing.

2.6 Conceptual Framework

To explore main research problem of consumer adoption of 3D printing, a model of unified theory of acceptance and use of technology (UTAUT2) is applied. The model was defined by Venkatesh et al. (2012) and is used to explain the behavioural intention of consumers to use a technology, such as additive manufacturing. Halassi et al. (2018) argue that while several other models to predict consumer adoption exist, UTAUT2 is superior by combining most crucial factors from other models. Furthermore, Hartmann and Vanpoucke (2017) have tested the validity of UTAUT2 model for technologies in their early stages and found no significant differences between early and later stage technologies in terms of their user acceptance. However, both Hartmann and Vanpoucke (2017) and Halassi et al. (2018) have adjusted the original UTAUT2 model by eliminating the factor of habit from the framework. They justify this modification based on a reasoning that as a new technology, consumers have not yet established habits towards 3D printing. As a further adjustment to the model, Hartmann and Vanpoucke (2017) and Halassi et al. (2018) also incorporate DIY mentality of users as an additional predictor. This addition supports the views explored in literature by Matias and Rao (2015) and Kietzmann et al. (2015) that currently 3D printing is mostly adopted by a group of experimenters called makers or tinkerers.

The conceptual framework is presented in Figure 1, with predictors of consumer's behavioural intention to adopt 3D printing presented on the left side. The dashed line makes a division of factors: performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, and price value, of the original UTAUT2 model by Venkatesh et al. (2012) and the added DIY mentality factor by Hartmann and Vanpoucke (2017) and Halassi et al. (2018). On the right side, six control variables: age, gender, nationality, education level, employment status and income, are displayed. Together, these variables help understand the behavioural intention of consumers to use 3D printing.

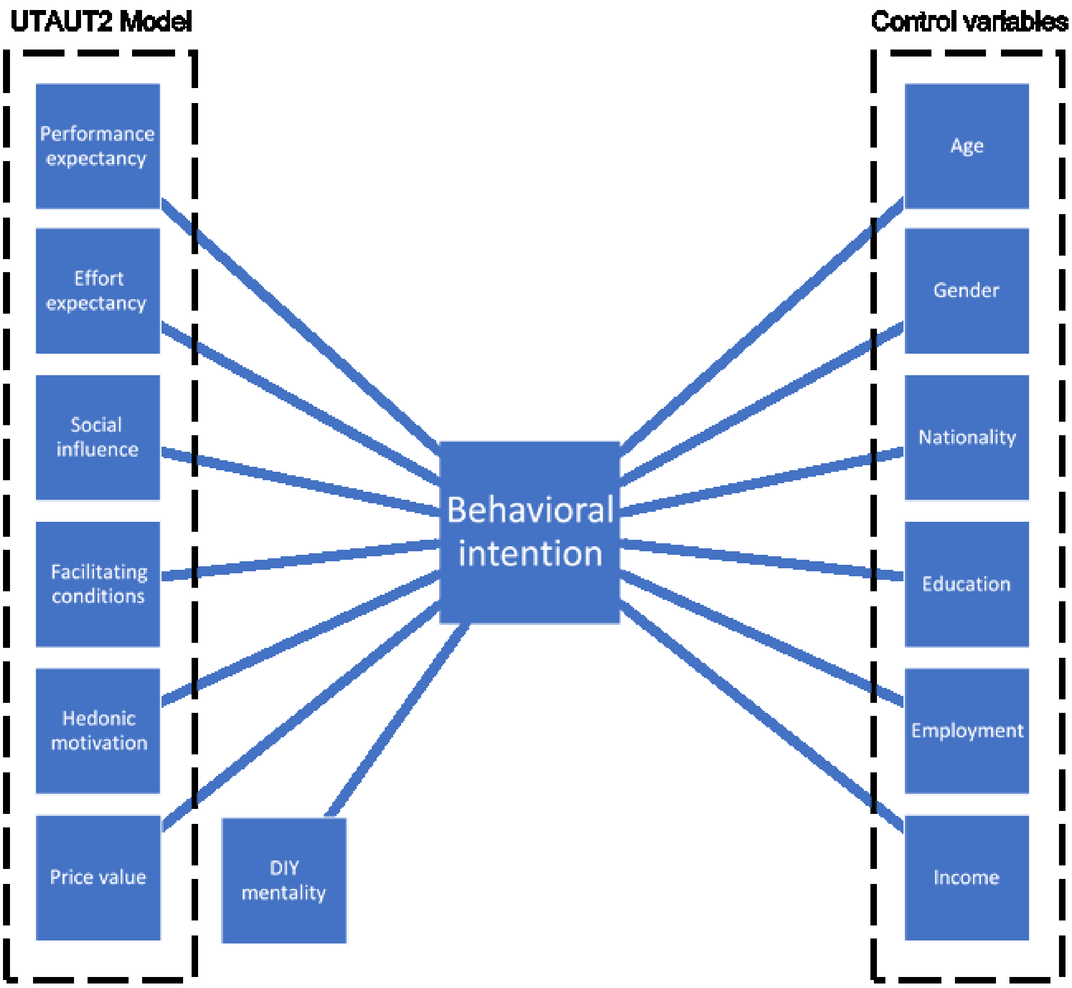

Figure 1: Conceptual framework (adapted from Halassi et al., 2018)

3. METHODOLOGY

3.1 Research Design

The objectives of the research were to:

- Find and measure factors affecting consumer 3D printing use
- Analyse the opportunities and weaknesses of 3D printing
- Define implications for consumers using 3D printing
- Explore business models in which consumers can adopt 3D printing

The opportunities and weaknesses of 3D printing were thoroughly discussed in the literature review. Additionally, the literature review explored user entrepreneurship, co-creation and co-design as well as crowdsourcing as potential models for consumers to utilize 3D printing for financial benefit. Some implications for consumers, for example the shift from consumers to 'prosumers', were also defined.

To analyse the factors affecting consumer 3D printing use, several hypotheses can be developed based on the UTAUT2 framework. Additionally, further definitions on the constructs are given.

Performance expectancy measures the benefits that consumers can get by using 3D printing technology. It is expected to have the strongest influence on behavioural intention and is tied to the concept of utility (Venkatesh et al., 2012). Furthermore, Venkatesh et al. (2003) predict that the effect is stronger for men and younger people. This hypothesis is assumed as men tend to be more task-oriented and focused on accomplishment, while younger people in general emphasize extrinsic rewards (ibid). Therefore, the following is hypothesized:

> H1: Performance expectancy positively influences the behavioural intention to use 3D printing technology, with the effect being more significant for men.

Effort expectancy measures the perceived easiness to use 3D printing technology. Venkatesh et al. (2003) furthermore argue that the effect of effort expectancy is higher for women and people of older age, as increased age affects cognitive and learning processes. Therefore, the following is hypothesized:

> H2: Effort expectancy positively influences the behavioural intention to use 3D printing technology, with the effect being more significant for women.

Social influence measures the effect on consumers' behaviour to use 3D printing technologies due to influence by other people. Venkatesh et al. (2003) argue the impact is caused due to social norms and the perceived image within a social system, with the effect being more significant for women. Therefore, the following is hypothesized:

> H3: Social influence positively influences the behavioural intention to use 3D printing technology, with the effect being more significant for women.

Facilitating conditions measures the support and resources available for consumers to use 3D printing technologies. Venkatesh et al. (2003) identify self-behaviour: e.g. willingness to invest in resources and knowledge to adopt 3D printing technologies, external facilitating conditions: e.g. guidance and instruction, and existing compatibility with other technologies. Therefore, the following is hypothesized:

> H4: Facilitating conditions positively influence the behavioural intention to use 3D printing technology.

Hedonic motivation measures the enjoyment consumers get or perceive to get from using 3D printing. Venkatesh et al. (2012) argue that fun is an important factor for consumers to accept and use a technology. Therefore, the following is hypothesized:

> H5: Hedonic motivation positively influences the behavioural intention to use 3D printing technology.

Price value measures the perceived value, or trade-off between the price to use 3D printing technology and the quality of the output. Venkatesh et al. (2012) point out that the cost of use is more important for consumers than for example employees at a workplace. A positive price value should increase the use of 3D printing. Therefore, the following is hypothesized:

> H6: Price value positively influences the behavioural intention to use 3D printing technology.

DIY mentality is tied to the use of 3D printing technologies as the regular users are often a group of experimenters (Kietzmann et al., 2015; Matias & Rao, 2015). Moreover, Hartmann and Vanpoucke (2017) predict that 3D printing allows DIYers to fulfil their needs of empowerment, uniqueness and sense of community. Therefore, the following is hypothesized:

> H7: DIY mentality positively influences the behavioural intention to use 3D printing technology.

Primary data collection method works best to test the hypotheses, as the constructs measured are strongly linked to consumer behaviour, skills, and attitudes. Furthermore, a quantitative research method was chosen over a qualitative one, since one of the aims of this research was to assess the applicability of the UTAUT2 framework in 3D printing. Quantitative research allows gathering precise numerical data to test the hypotheses accurately. Therefore, a questionnaire developed by Halassi et al. (2018) was utilised. The questionnaire is based on the UTAUT2 model presented in the literature review.

As a reason to replicate the research conducted by Hartmann and Vanpoucke (2017) and Halassi et al. (2018) is that both studies indicate a potential difference in research findings depending on the geographical area of the respondents. The studies considered only German and Dutch consumers, respectively, and Hartmann and Vanpoucke (2017) suggest taking into account geographical differences in future studies. As such, this research and data collection was conducted in English with the aim to widen the applicability of the findings.

Although similar in nature, the studies by Hartmann and Vanpoucke (2017) and Halassi et al. (2018) have some differences. The former authors have further divided the behavioural intention to general, self-design, and self-production purposes. Halassi et al. (2018), however, only measure the general intention but also add additional control variables of nationality and income. Furthermore, Halassi et al. (2018) have expanded the construct of behavioural intention by including measurements of purchase intention that Hartmann and Vanpoucke (2017) lack. As discussed previously, consumers may be able to use 3D printing services without buying one, for example via fablabs or crowdsourcing. Being able to discern these different types of uses is important for the purposes of this research, thus the questions developed by Halassi et al. (2018) are chosen.

All questions in the questionnaire not including the control variables were measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The questions are presented below in Table 1 along with the constructs they aim to measure, in the same order as in the questionnaire. The control variable questions were placed at the end of the questionnaire. The gender of the participants was measured on a dichotomous scale (1 = male, 2 = female). Both age and income were measured by giving a range of ages (7 options) and incomes (11 options). Income was measured as annual income. In terms of employment, participants were asked to select their current employment status (7 options) and for education, the participants stated the highest level of education achieved (5 options). For nationality, the concept was phrased as “Where do you come from”, allowing participants to select from a list of countries. The control variables and their categories, excluding the nationality, are displayed in Table 2.

Construct	Items
Performance expectancy (PE)	1. I think 3DP is useful 2. Using 3DP could help me accomplish things more quickly 3. Using 3DP can increase my productivity
Effort expectancy (EE)	1. Learning how to use 3DP will be easy for me 2. My interaction with 3DP is clear and understandable 3. I think 3DP is easy to use 4. I think it is easy for me to become skillful at using 3DP
Social influence (SI)	1. I expect that people, who are important to me, will think that I should use 3DP 2. I expect that people, who influence my behaviour, will think that I should use 3DP 3. I expect that people, whose opinions that I value, will prefer that I use 3DP
Facilitating conditions (FC)	1. I would be willing to invest in the resources necessary to use 3DP 2. I would be willing to invest in the knowledge necessary to use 3DP 3. 3DP is compatible with other technologies I use
Hedonic motivation (HM)	1. Using 3DP seems to be fun 2. Using 3DP seems to be enjoyable 3. Using 3DP seems to be very entertaining
Price value (PV)	1. 3DP is reasonably priced 2. 3DP is good value for the money 3. At the current price, 3DP provides a good value
DIY mentality (DIY)	1. I do my own home improvement projects because I enjoy the process 2. Performing my own maintenance makes me feel more engaged 3. I fix things myself, like household appliances, because I like to reuse and recycle 4. I find that I can save much money by doing things myself 5. Making things myself allows me to make what I need 6. I make products myself so they match me or my home 7. I design things myself because stores often do not have what I want 8. To get the right size for things I need (e.g. in my home) I have to make it myself 9. To get products that are compatible with my home I make them myself 10. To get products that match the style of my home, I have to make things myself
Behavioural intention (BI)	1. I intend to start using 3DP in the future 2. The probability is high that I will try to use 3DP in the future 3. The probability is high that I plan to start using 3DP frequently in the future 4. I would intend to purchase a 3D printer for home-use 5. My willingness to buy a 3D printer is high 6. I am likely to purchase any 3D printer 7. I would tell my friends to purchase a 3D printer for home-use.

Table 1: Measured constructs and items

Variable	Category
Gender	Male Female
Age	Under 18 18-24 25-34 35-44 45-54 55-64 65 or older
Education	Less than high school High school degree Bachelor’s degree Master’s degree Doctorate
Employment	Student Employed full time Employed part time Unemployed looking for work Unemployed not looking for work Entrepreneur Retired
Annual income	Less than 10 000 € 10 000 – 19 999 € 20 000 – 29 999 € 30 000 – 39 999 € 40 000 – 49 999 € 50 000 – 59 999 € 60 000 – 69 999 € 70 000 – 79 999 € 80 000 – 89 999 € 90 000 – 99 999 € More than 100 000 €

Table 2: Control variables and categories

3.2 Data Collection

The data was collected via an online questionnaire developed with Webropol. The questionnaire was tested before publishing with a test group of three family members. Link to the questionnaire was sent to university students via email and additionally shared on social media channels, namely on Facebook and Whatsapp. The questionnaire was conducted completely in English to maximise responses from as many nationalities as possible.

To make sure all respondents had sufficient knowledge of 3D printing, they were asked to watch a short explanatory video about the technology. A link to the video was presented on the same page with the questions to allow respondents to refer back to the video, if necessary.

4. FINDINGS

4.1 Descriptive Statistics

A total of 47 respondents filled in the online questionnaire. 45 respondents (96% of all responses) were in the age group of 18-24 years old. Considering the survey was shared with Bachelor level students as well as on social media, the result was predictable. Only 1 respondent reported to be under 18 years old while only 1 respondent was between 25-34 years old. As such, testing the hypotheses by looking at the effect of age would not provide reliable results.

In terms of gender, 19 respondents (40% of all) were male and 28 female (60% of all responses). As such, the responses are well balanced by gender and allows reliable comparison of the two.

Out of all 47 respondents, 39 were students (83% of all responses). Again, the finding is not surprising due to how the questionnaire was shared. 4 reported to be employed full time (9% of all responses) while 3 were employed part time (6% of all responses). Only 1 respondent was unemployed looking for work (2% of all responses).

As for education level of the respondents, 3 had a less than high school degree (6% of all responses). High school degree was the highest level for 26 respondents (55% of all responses) and a bachelor's degree for 15 respondents (32% of all responses). Only 3 respondents had completed a master's degree (6% of all responses), with no doctorate level respondents. Overall, two groups can be distinguished from the responses, those with no university degree (62% of responses) and those with one (38% of responses).

Despite a high frequency of students responding to the survey, only 30 respondents earned less than 10 000 € (64% of all responses). This may be due to some students working alongside their studies or due to capital income. 14 respondents reported to earn between 10 000 € - 19 999 € (30% of all response), with only 2 respondents earning 20 000 € - 29 999 € (4% of all responses) and 1 with earnings between 30 000 € - 39 999 € (2% of all responses). Thus, two groups can be identified from the responses: those with income below 10 000 € (64% of responses) and those above it (36% of responses). However, no respondent reported earnings over 40 000€.

In terms of nationality, despite a large number of non-Finnish people the survey was sent to, as many as 35 respondents (75% of all responses) were Finnish. All other countries: China, France, Germany, Kazakhstan, Norway, Slovenia, Switzerland, Turkey, the U.S., and Vietnam, had only 1 respondent, with only India with 2 respondents. Overall, the participants can be divided into two groups: Finnish people (75% of respondents) and others (25% of respondents).

4.2 Reliability Testing

To measure the reliability of the constructs, Cronbach's alphas were calculated for each of the constructs.

The construct of performance expectancy has a Cronbach's alpha of 0.773, signifying an acceptable level of reliability. By removing the question "I think 3D printing is useful”, the Cronbach’s alpha would increase to 0.825; thus, the question might not measure the benefits achieved by 3D printing technology that the two other questions in the construct do. Overall, the participants think 3D printing is useful (M=4.40, SD=0.80) but the benefits of accomplishing things faster (M=3.17, SD=1.00) and increasing productivity (M=2.98, SD=0.99) are less agreed upon. This may be due to lack of familiarity with the technology.

Effort expectancy has a Cronbach’s alpha of 0.850, which is a good sign of reliability. Removing any of the items in the construct would lower the alpha. Similar to performance expectancy, the lack of current experience with 3D printing may be visible: respondents agree more that learning the use of 3D printing is easy (M=3.06, SD=0.99) than that their interaction with 3D printing is clear (M=2.72, SD=0.90).

The construct of social influence has a Cronbach’s alpha of 0.912. This is an excellent level of internal reliability. However, participants of the survey generally slightly disagree with the items within the construct, perhaps signifying social influence does not generally affect the use of 3D printing.

Facilitating conditions has an acceptable Cronbach’s alpha of 0.740. However, removing any of the items in the construct would lower the Cronbach’s alpha. There are also significant deviations between the willingness to invest in resources (M=2.64, SD=1.11) and knowledge (M=3.43, SD=1.16) to use 3D printing. Thus, it seems consumers in the sample are more willing to improve their 3D printing knowledge than to invest in resources to use it.

Hedonic motivation has a good Cronbach’s alpha of 0.868 and removing any of the items within the construct would decrease the alpha. Overall, the questionnaire participants somewhat agree with the items within the construct: in particular, 3D printing is perceived as fun (M=4.19, SD=0.77) and enjoyable (M=3.85, SD=0.81).

The construct of price value has a Cronbach’s alpha of 0.824, which is a good level of reliability. Removing any of the items would decrease the alpha of the construct. Overall, the respondents of the survey are uncertain about the reasonable pricing (M=2.81, SD=0.95) and the value of 3D printing technology (M=2.94, SD=0.76). This may be again caused due to the unfamiliarity with the technology or its costs by consumers.

Despite ten items within the construct, DIY mentality has an excellent internal reliability with Cronbach's alpha of 0.914. The most significant reason for the respondents to do things themselves is to save money (M=3.87, SD=1.03), while the aspects of having to do things oneself to get the right size (M=2.40, SD=1.15), compatibility with home (M=2.53, SD=1.18) or match the style of home (M=2.55, SD=1.30) are less agreed by the respondents.

4.3 Control Variables

The control variables: gender, education level, income, and nationality were arranged into variables with two options: male and female, no university degree and university degree, less than 10 000 € a year and more than 10 000 € a year, and Finnish and non-Finnish, respectively. T-tests were conducted for all constructs by looking at potential differences between respondent groups.

In terms of gender, the only construct with significant differences is price value. Women (M=3.11, SD=0.67) consider price value significantly more important than men (M=2.49, SD=0.69), $t(45)=-3.067$, $p<0.004$. The difference was not predicted in the hypotheses despite its strong significance.

For education level, the constructs of hedonic motivation and performance expectancy had significant differences between the two groups. For people with no university degree completed (M=4.07, SD=0.64), hedonic motivation was more important than for people with at least one university degree (M=3.61, SD=0.83), $t(45)=2.133$, $p<0.038$. Additionally, in terms of performance expectancy, the effect was similar: respondents without a university degree (M=3.74, SD=0.61) considered the construct more important than those with one (M=3.17, SD=0.90), $t(45)=2.589$, $p<0.013$. As respondents with the highest education level of high school diploma are likely younger, the hedonic motivation might be more important for younger people. Likewise, performance expectancy measuring the benefits achieved through 3D printing might be more important for younger people, who emphasize external rewards.

In terms of income level, only the construct of hedonic motivation had significant differences between the two groups. For those earning below 10 000 € per year (M=4.07, SD=0.73) the importance of hedonic motivation was higher than those earning more than 10 000 € (M=3.59, SD=0.67), $t(45)=-2.211$, $p<0.032$. The reason for the differences might follow the same logic as for education level that the importance of enjoyment is higher for younger people.

In terms of nationality, significant differences between Finnish and non-Finnish people can be found again in hedonic motivation, performance expectancy but also in social influence. Hedonic motivation is more important for non-Finnish people (M=4.39, SD=0.57) than for Finnish people (M=3.72, SD=0.73), $t(45)=2.883$, $p<0.006$. Similar results can be found in performance expectancy: non-Finnish people (M=3.94, SD=0.51) view it more important than Finnish respondents (M=3.37, SD=0.80), $t(45)=2.307$, $p<0.026$. Finally, same results are present for social influence: non-Finnish respondents (M=2.75, SD=1.07) consider it more important that Finnish respondents (M=2.07, SD=0.79), $t(45)=2.351$, $p<0.023$.

To summarise, the construct of hedonic motivation had overall the most significant differences between the four control variable groups, along with performance expectancy.

4.4 Hypotheses Testing

The hypotheses were tested in SPSS using linear regression. Each of the constructs were formed by taking the arithmetic average of the items in the construct. Behavioural intention was selected as the dependent variable for each of the regression tests, with the independent variable being the construct that is measured.

First, all constructs are measured alone as a predictor for behavioural intention to use 3D printing. Performance expectancy acts as a slight predictor to behavioural intention, *$F(1, 45)=18.627$, $p<0.000$, $R=0.541$, $R^2=0.293$*. Effort expectancy predicts the behavioural intention slightly less, *$F(1, 45)=11.603$, $p<0.001$, $R=0.453$, $R^2=0.205$.* Social influence has almost the same impact as effort expectancy, *$F(1, 45)=11.742$, $p<0.001$, $R=0.455$, $R^2=0.207$.* Finally, out of all the original factors in the UTAUT model (Venkatesh et al., 2003), facilitating conditions predict the behavioural intention the most, *$F(1, 45)=31.164$, $p<0.000$, $R=0.640$, $R^2=0.409$.* Therefore, it seems the consumer willingness to invest in resources and knowledge to use 3D printing is the most influential predictor in 3D printing adoption.

Out of constructs added in the UTAUT2 model by Venkatesh et al. (2012), hedonic motivation has very little impact on the behavioural intention of consumers, *$F(1, 45)=3.586$, $p<0.065$, $R=0.272$, $R^2=0.074$.* Although the result is outside the selected 95% confidence interval, the linear relationship between the constructs is weak. Price value has even lesser impact, *$F(1, 45)=1.159$, $p<0.287$, $R=0.158$, $R^2=0.025$*, although the significance of the relationship is low.

Finally, the added construct of DIY mentality slightly predicts the behavioural intention to use 3D printing, *$F(1, 45)=9.817$, $p<0.003$, $R=0.423$, $R^2=0.179$*. However, the effect is not as strong as the constructs in the original UTAUT framework.

Conducting a multiple regression with all the constructs as predictors and behavioural intention as the dependent variable, three constructs predict the use of 3D printing most significantly: facilitating conditions, price value, and performance expectancy, *$F(1, 43)=4.537$, $p<0.039$, $R=0.713$, $R^2=0.508$.* Adding a fourth predictor, DIY mentality would not significantly improve R^2, with the value even decreasing by adding a fifth predictor of social influence. Therefore, by looking at the whole constructs as predictors for behavioural intention to use 3D printing, facilitating conditions, price value, and performance expectancy seem to be the best ones. However, an arithmetic average might not describe the constructs most accurately, as some items within each construct have variability in terms of answers.

To avoid the issue of using constructs as a whole to predict the consumer use of 3D printing, individual questions can be examined using multiple regression. Using this method, four predictors act as the most significant predictors for behavioural intention to use 3D printing. The predictors include 3D printing increasing productivity, willingness to invest in resources to use 3D printing, 3D printing providing good value, and 3D printing being easy to use, $F(1, 42)=4.791$, $p<0.034$, $R=0.791$, $R^2=0.625$.

The constructs associated with these items are performance expectancy, facilitating conditions, price value, and effort expectancy, respectively. Overall, it seems using individual items as predictors provides a stronger estimate of factors influencing 3D printing adoption. The difference may be caused as all items within each construct may not necessarily measure the same thing, despite all constructs having at least an acceptable level of internal reliability.

To relate the above discussion to the hypotheses presented, H1 can be partially confirmed. Performance expectancy does positively impact the behavioural intention to use 3D printing, but there seems to be no difference between men and women. Overall, the results align with predictions of Venkatesh et al., (2012) in that the construct acts as the strongest predictor.

H2 can be partially confirmed as well, as in particular the ease of use of 3D printing positively influences the behavioural intention to use 3D printing. However, the whole construct did not provide significant results as a predictor. Moreover, there were no significant differences between women and men.

There seems to be no evidence for H3, and thus needs to be rejected.

H4 can be confirmed, as facilitating conditions positively influence the behavioural intention to use 3D printing technologies. In particular, the willingness to invest in necessary resources is significant.

There seems to be no evidence for H5, and thus needs to be rejected.

H6 can be confirmed. Price value, and in particular 3D printing providing good value at the current price, acts as a predictor to use 3D printing technology. However, the whole construct is not a significant predictor.

Finally, H7 needs to be rejected, too, as there is no evidence for DIY mentality acting as a predictor.

5. DISCUSSION AND ANALYSIS

5.1 Comparison with Previous Studies

As the research aims to replicate the research by Halassi et al., (2018), the results should be comparable despite differences in hypotheses testing. Differences exists, however.

As discussed above, the confirmed hypotheses in this research are H1 (performance expectancy), H2 (effort expectancy), H4 (facilitating conditions), and H6 (price value). Halassi et al. (2018) however, only found support for hypotheses H4 (facilitating conditions), H5 (hedonic motivation), and H7 (DIY mentality). Thus, the only similarly seems to be facilitating conditions, being the strongest predictor in both studies. Yet, despite different predictors, this research explains about 62% of the variance in the behavioural intention to use 3D printing, while the study by Halassi et al. (2018) explained 67% of the variance in dependent variable. Therefore, although the predictors are different, the factors in UTAUT2 framework allow predicting the consumer intention to use 3D printing at least to some extent.

The impact of price value in this research may be explained by the large portion of young respondents. Younger people may be more conscious about their money and the value they get for it, while older people with higher income may not be as sensitive to its effect.

However, as to why there are differences between the studies regarding effort expectancy, hedonic motivation, and DIY mentality, the reasons may not be as clear. In particular, due to older respondents in the study by Halassi et al. (2018), it would seem more likely that effort expectancy would be more influential in their study. However, effort expectancy being a predictor of consumer use of 3D printing technology is aligned with the initial predictions of Venkatesh et al. (2003), which would support its significance in this study.

In terms of DIY mentality, the difference in results might imply the items used to measure the construct are not good in providing consistent results. Although Hartmann & Vanpoucke (2017) also found evidence for the impact of DIY mentality on 3D printing use, the question items used were different from those by Halassi et al. (2018). Particularly, Hartmann & Vanpoucke (2017) included more items regarding the economic benefit of DIY approach, which aligns well with the influence of the construct of price value in this study. Future research into the different aspects of DIY mentality might provide further findings regarding the construct.

5.2 Implications for Users

Relating the findings to the concepts discussed in the literature review, facilitating conditions are overall the most important factor for consumers to adopt 3D printing. Consumers need to be willing to invest in both resources and knowledge to use 3D printing. The latter reflects educational aspects: consumers should be curious and interested to learn more about 3D printing. Additionally, help and support needs to be available for consumers to fully adopt 3D printing technology at home, supporting the idea that 3D printing requires specific technical skills to be used effectively.

The significance of the price value is also important considering the 3D printing applications for consumers. Since consumers often lack practical personal experience with the technology, the benefits associated with the technology might be intangible for them. This might make it difficult for consumers to assess the value of 3D printing, thus making them sensitive to the price. Overall, consumers might also not be aware of the price of consumer-level 3D printers and evaluating them more expensive than they in reality are.

Related to the required skills to utilise 3D printing technology, it is of little surprise that effort expectancy is an important factor in consumer 3D printing usage. Developing systems that are easy to use for consumers might, on the other hand, imply developing 3D technologies that have limited functions. This might consequently limit the consumers' ability to use 3D printing for business or entrepreneurial purposes. Yet, having convenient systems for consumers is likely the first step for more widespread adoption of 3D printing at homes.

5.3 Review of Research Objectives

The objectives of this research were to:

- Find and measure factors affecting consumer 3D printing use
- Analyse the opportunities and weaknesses of 3D printing
- Define implications for consumers using 3D printing
- Explore business models in which consumers can adopt 3D printing

Although factors influencing consumer 3D printing use differ from previous studies, the research confirmed four statistically significant hypotheses. The results, for example the skills required to utilise 3D printing and the cost of the technology are aligned with the existing literature. However, it is surprising DIY mentality had no effect on 3D printing adoption according to research, despite literature discussing makers or tinkerers as a significant group of users.

The opportunities and weaknesses were analysed in the literature review. Yet, somewhat differing views exist in terms of how 3D printing will be adopted in comparison to other technologies, such as personal computers. Additionally, further research into 3D printing's effects into global trade could provide more definite conclusions.

In terms of implication for consumers and business models, 3D printing may provide further opportunities for consumers to participate in design and manufacturing processes of products. Consumers may use the technology for business purposes and become user entrepreneurs or simply develop more customised products for their personal use. Consumer adoption of 3D printing will likely increase the communality of users, resulting in joint design efforts by consumers or in further crowdsourcing opportunities. Companies may need to explore how to utilise the resources consumers can bring into product development using 3D printing technologies, while being aware of intellectual property challenges.

5.4 Limitations

The sample size in the study was relatively small with slightly less than 50 responses. In particular, the low number of respondents might have affected the control variable tests, e.g. the effect of gender on various constructs. Furthermore, having a larger sample size would likely provide more reliable regression analysis results.

Furthermore, having more international respondents would have allowed more detailed analysis of the impact of nationality on 3D printing use. Incorporation of nationality in the analyses as either Finnish or non-Finnish does not allow drawing accurate conclusions on the factors behind the effects.

The way the questionnaire was distributed limited the age of the respondents as it was mostly shared with young people. Furthermore, distributing the survey directly to Bachelor level students likely affected the results on education level and partially income, too.

Finally, looking at the constructs by taking the arithmetic average might not accurately measure the construct. In particular for behavioural intention that was used as the dependent variable for all regression analysis, excluding some of the items could provide different results.

6. CONCLUSIONS

6.1 Main Findings

Literature review in this study explored the advantages and weaknesses of 3D printing, the concept of user involvement, and the connection between business models and 3D printing.

Main advantages of the technology include easier product customisation, simplified supply chains, faster product development, and cost savings. The main weaknesses, however, are intellectual property issues, skills required to use 3D printing effectively, and current technological obstacles. Understanding both helps companies and users to utilise 3D printing in areas where it is most effective.

Adopting 3D printing helps consumers to become user entrepreneurs, utilising the technology for financial gains. Alternatively, users can design or manufacture products in cooperation with companies either by themselves or via collaborative methods, such as fablabs or design communities. Yet, intellectual property questions, cost of technology, and high level of skills required may pose challenges for users.

Finally, 3D printing may augment business models where communality and sharing are important. Crowdsourcing is the most prominent example of such model. Consumers may take on further roles in the product development process, in particular in niche product markets where need for customisation is high.

The quantitative research conducted in this study aimed to find and measure factors affecting consumer 3D printing use. A questionnaire based on existing UTAUT2 framework was used for the research.

Based on the findings of the questionnaire, the consumer adoption of 3D printing is predicted most significantly by the performance expectancy (benefits linked to 3D printing), effort expectancy (easiness to use 3D printing), facilitating conditions (support and resources available to adopt 3D printing), and price value (perceived value of 3D printing).

6.2 Implications for International Business

Further adoption of 3D printing by consumers might lead to more localised production with higher customisation opportunities. Companies need to be aware of the future potential of 3D printing and co-creation to utilise user knowledge and consumer demand to their full capacity. Design of objects and products might shift more towards consumers, and manufacturers may need to be more flexible, in particular if they compete by product customisation. Manufacturers might also need to pay close attention to intellectual property of their products, as 3D printing technology allows easier product replication and reproduction.

6.3 Suggestions for Further Research

Further research could be conducted to analyse the impact of overall technological experience and existing knowledge of 3D printing on the intention to use the technology. Additionally, as programming and digital skills are being adopted by countries in their education systems, future research could consider potential differences caused by this.

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