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Customer Participation and Product Innovation in the Era of Industry 4.0 and 3D Printing: Evidence at Firm and Individual-Level

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DEDICATION

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Thesis Introduction

My PhD dissertation consists of two chapters which empirically analyse the impact of the modern technologies of Industry 4.0 on customer participation (CP) in new product development (NPD) process of firms in general, and the impact of 3D printing on individual-level innovation performance in particular. These studies aim to contribute to the debate on the evolution of CP from customers as passive recipients of products offered by firms to independent makers of their desired products.

Initially, customers had no input in what was offered to them, and they were the submissive recipients of firms' products. The market was perceived as the aggregate of demand and value transfer, whereas companies were the points of value creation (Kotler, 2002; Vargo & Lusch, 2004). With the advent and omnipresence of the Internet, information asymmetry reduced between firms and customers. As a result, the customers started taking part in the NPD process as mere information providers to active partners. Consequently, active customers happened to appear as lead users (Von Hippel, 1986) whose opinion carried weight which could influence the changes in product features and subsequent adoption of products by other customers. Companies also realized the importance of customers' feedback and opinion; hence, CP evolved further, and customers were provided with toolkits (Von Hippel, 2001b). "User toolkits for innovation" provided customers with a free environment within defined bounds related to specific products and allowed them to develop their customized products via trial-and-error. Customers also started forming virtual customer communities (Nambisan, 2002) to discuss the ideas and information regarding products and desired new features. But it is the recent work which has given formal recognition to CP in NPD (Chang & Taylor, 2016) by acknowledging various participation roles a customer can take on in NPD, e.g. a customer as an information source, a co-developer and an innovator (Cui & Wu, 2016; 2017).

The world is forecasting the fourth industrial revolution prompted by advanced technologies, and the twenty-first century demands technological innovation and novel product development approach (L. Li, 2018a). The term 'Industry 4.0' (German: Industrie 4.0) – representing the much-anticipated fourth industrial revolution symbolising the increased use of modern technologies in the manufacturing process of firms – was coined at 'Hannover Messe 2011' in Germany as part of its high-tech strategy to sustain the competitive advantage and meet the requirements of future production. Other countries have also initiated similar ventures and use different terminologies like 'Internet of Things' in the United States and 'Made-in-China 2025' in China to represent the phenomenon of Industry 4.0. Consequently, there is an increasing trend of investment by firms in the technologies associated with Industry 4.0. Although some of these technologies like robotics, 3D printing, laser cutting are in use since over two decades, many of Industry 4.0 applications necessitate the combination of these technologies (Xu et al., 2018). However, the connectivity between these technologies is not extensively discussed before 2011. But now, the discussion has started as the technologies have reached a mature state of application and are materialized under the concept of Industry 4.0 (Santos et al., 2017). According to Gilchrist (2016), "Industry 4.0 is essentially a revised approach to manufacturing that makes use of the latest technological inventions and innovations, particularly in merging operational and information and communication technology."

The first chapter of this thesis is a firm-level analysis which focuses on analysing the impact of Industry 4.0 technologies on CP in firms' NPD process where customers work as co-developers. Customer participation is defined as the magnitude of the customer's engagement in the company's NPD process (Fang, 2008). Scholars consider the investment in modern technologies a significant internal factor to cater to customized demand of consumers (Kotha, 1996). Industry 4.0 technologies are interactive because of the digital connectivity of tools and remote inputs and have the potential to take the magnitude of customer's participation to a higher level and engage them in the product design and production process. Hence, it is essential to empirically investigate this claim as the Industry 4.0 technologies will not only help to develop new products and services (Lee et al., 2014), but the provision of customized products will also help to reduce the number of goods returned. For empirical analysis, we collected the data from 123 North Italian firms by using a structured questionnaire targeted to chief operating officers or managers in charge of technological and manufacturing processes. The firms were currently using Industry 4.0 technologies like 3D scanner, additive manufacturing, IoT and intelligent products, robotics, big data and cloud, augmented reality and laser cutting.

Another facet of recent technological scenario is that it takes the empowerment of customers and end-users one step further from toolkits and customer communities. Now some technologies are in direct reach and use of individuals. One potentiality linked with such technologies, especially 3D printing (3DP), is the transformation of customers into real "*makers*" (Anderson, 2012). 3DP is "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" (ASTM, 2012). A computer-aided design (CAD) file of the object idea is generated by using a software which contains all the information of the physical object. To develop the physical object, the 3D printer receives the print command and based on the digital file, transforms the information in the arrangement of material layers upon layers. As the material layers bind together directly from a CAD file, it reduces the product development time and intensity of physical flows (Holmström et al., 2017). The additive style of manufacturing also eliminates many intermediaries like labour (Ford & Despeisse, 2016) and expensive and time-consuming tools. 3DP is ideal for the economies-of-one and is not resource-intensive. These features make 3DP ideal for end-user and open innovation. Subsequently, 3DP aids firms as well as individual makers to execute a project from the design stage to final output (Rayna & Striukova, 2016a).

Apart from knowledge creation and social exchange, the use of technology forms the basis of the relationship of makers movement with entrepreneurship (Browder et al., 2019). The prices have decreased considerably, and 3DP is in access to end-user and makers. Recent research shows that makerspaces are significant platforms for 3DP spread and adoption (Woodson ey al., 2019). 3DP has the potential to empower makers and boost end-user innovation and entrepreneurship linked with the maker movement. Despite the increasing importance and relevance of 3DP, very little is known about the factors affecting the acceptance and use of 3DP among the exiting users. More importantly, the impact of the use of 3DP on innovation performance is not empirically acknowledged at individual-level.

The second chapter is an individual-level empirical analysis of the factors affecting the acceptance and use of 3DP by makers in makerspaces. Makerspaces have been used as local places of shared resources and provision of manufacturing technologies that are not as commonly available as internet connectivity and computers (Kostakis et al., 2015). This chapter uses an extended model of the unified theory of acceptance and use of technology 2 (UTAUT2) (Venkatesh et al., 2012) to explore the factors affecting the acceptance and use of 3DP by makers. The model is extended on the outcome side to analyse the impact of the use by incorporating a new construct, 'innovation performance' as a consequence of use. For empirical analysis, I developed a survey, using the scales validated by exiting studies and distributed it to the visitors of makerspaces registered on three platforms; hackerspaces.org, makerspaces.make.co and fabfoundattion.org and had the facilities of 3DP. In total, 338 responses were used for the empirical analysis of the study.

The results of the first chapter confirm that the use of Industry 4.0 technologies does have a positive impact on CP in the development of product design and production process of the firms. The effect is stronger for CP in design than CP in the production process. The firms which report product flexibility as their competitive advantage, are more like to allow CP in the product design and production process. The findings of the second chapter, focused at the individual-level adoption and impact of 3DP on innovation performance, show that the makers are adopting 3DP printing because they expect an increase in their performance and the opinion of the important people around them also matters in the adoption decision. Empirical results indicate that the adoption of 3DP also depends on the availability of facilitating conditions and the hedonic motivation extracted from the use of 3DP. The results also provide empirical evidence of the impact of the use of 3DP on makers' innovation performance.

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Customer Participation in New Product Development: An Industry 4.0 Perspective

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Abstract

Manifested in the intensive use of modern technologies, the rise of the fourth industrial revolution commonly referred to as 'Industry 4.0' is inevitable. Due to digital connectivity, the technologies of Industry 4.0 are interactive and are expected to facilitate the profitable production of individually customized products. But the literature lacks the empirical studies analysing their impact on customer participation (CP) in new product development (NPD). By using the data of 123 'Made in Italy' manufacturing firms which are using these technologies and belong to 9 industries (automotive, rubber, electronics, jewellery, eyewear, clothing, sportswear, leather, textile), this study explores firms' perspective of the use of Industry 4.0 technologies in allowing CP in NPD stage; product design and production process. Results confirm that among the adopters of Industry 4.0 technologies, firms which embrace more technologies allow more CP in the product design and production process of products. Individual technology analysis shows industry-specific and technology-specific effects on CP in product design and production process. Use of augmented reality indicates a strong positive impact on CP in both, product design and production process of firms. Additive manufacturing has a positive impact on CP in product design, while Big Data has a negative effect on CP in the production process. Implications for theory and practice are also discussed.

Keywords: Industry 4.0, Customer participation, new product development.

1. Introduction

Courtesy the emergence of new communication and information technologies, transparency between customers and firms have increased (Nambisan, 2002) and a higher number of firms are assuring customer participation (CP) in their new product development (NPD) process (Fang, 2008). Initially, the firms started listening to the "voice of the customer" in pursuit of identifying their unmet needs and solutions (Griffin & Hauser, 1993). Now, CP has evolved to a point where firms accept customer inputs during all phases of the NPD process (Morgan et al., 2018). CP is defined as the magnitude of customer's engagement in company's NPD process (Fang, 2008). The current approach of CP is different from the traditional one in that now customers are not mere informants; instead they work as co-developers of products and their efforts contribute a substantial portion of NPD (Fang, 2008). Concepts like lead users and virtual customer communities have appeared in the literature (Von Hippel, 1986; Nambisan, 2002) in end-user innovation theories. But more recent work gives formal recognition to CP in NPD (Chang & Taylor, 2016) by acknowledging various participation roles a customer can take on in NPD like a customer as an information source, a co-developer and an innovator (Cui & Wu, 2016; 2017). CP has evolved as the "beating heart" of marketing (Walter, 2012), and it is "the future for all of us" (Forbes, 2014).

"Customer participation per se is not new" (Bendapudi & Leone, 2003, p. 14). Existing studies have affirmed that CP helps to create product innovation (Fang, 2008), economic (Hibbert et al., 2012) and relational values (Troye & Supphellen, 2012). However, CP is an under-researched area (Sugathan et al., 2017). The initiatives taken inside the firms to enhance CP in product development are rarely discussed. Scholars consider the investment in modern technologies a significant internal factor to cater to customized demand of consumers (Kotha, 1996). Yet such studies mainly focus on the technical aspects of technologies and infrequently discuss the strategic view of their adoption. A strategic perspective seems crucial to understand how a firm can successfully incorporate customers' input (Cui & Wu, 2018). Recently, Ramaswamy and Ozcan (2018) attempt to refresh the conceptualisation of co-cocreation (what we call "customer participation" in this paper) and state that "merely looking at the phenomena of co-creation through the lens of activities that tended to dominate the literature, missed the weaker signals of interactional creation, which was being enhanced by a new age of interconnections catalyzed by technology and digitalization." (p. 197).

We contend that the emerging technological scenario of the fourth industrial revolution, famously referred to as "Industry 4.0" provides an interactive platform to produce customized products. Researchers believe that product development, i.e., product design and engineering process (Chang & Taylor, 2016) could be a potential field to be benefited from these technologies (Rauch et al., 2017). Industry 4.0 is characterized by the use of modern technologies in the NPD process and support a higher percentage of customized production. Schwab (2016), the founder and executive chairman of the World Economic Forum, also associates the trend of "technology-enabled platform" with Industry 4.0. The technologies of Industry 4.0 are interactive and digitally connected. Products manufactured through these technologies have a higher value as customers can participate in the value creation process with the help of these technologies (Rayna & Striukova, 2016a). Hence, companies are getting closer to the technologies of Industry 4.0 for product development purposes (Rauch et al., 2016). For example, technologies like Internet of Things (IoT), Robotics, Big Data analytics (Gress & Kalafsky, 2015) and direct digital manufacturing, an umbrella term which includes technologies like additive manufacturing and 3D printing (Holmström et al., 2016), help to manufacture individually customised products.

As the concept of Industry 4.0 ages less than a decade, the researchers have varying understanding of the use of these technologies in smart and interactive manufacturing. Industry 4.0 is portrayed as a revolution in the manufacturing paradigm and is expected to prompt the profitable production of individually customized products. Despite the growing interest of researchers and practitioners in Industry 4.0 (Liu & Xu, 2016), the empirical analysis of the impact of these technologies on engaging customers in NPD remains scarce. Liao et al.'s (2017) systematic literature review reveals that Industry 4.0 studies are dominating the subject areas like computer science and engineering while the number of articles in the field of business and management is almost negligible. Most of the discussion on Industry 4.0 technologies is an observatory, and the extant literature has sparse empirical evidence validating the firm's perspective towards Industry 4.0 (Lin et al., 2018).

Industry 4.0 technologies are interactional because of the characteristics to be digitally connected and have their specific features and functions. Augmented reality, 3D printing and additive manufacturing, for example, have the reputation of developing a computer-aided design, building prototype and digitally visualizing the design and production process. Use of robotics and laser cutting provides automation of work. Big Data and Inter of Things (IoT) are primarily related to connecting physical and virtual components of the manufacturing facilities and collecting product usage and customers related data. Extant literature has studied the impact of these technologies individually. However, the connectivity between these technologies is not extensively discussed before 2011, but now it is enabled when the technologies have reached a mature state of application and are materialized under the concept of Industry 4.0 (Santos et al., 2017). We argue that the companies which adopt Industry 4.0 technologies intensively are better able to allow CP in the product development stage. We empirically analyse this proposition by using the data of Northern Italian companies which are already using Industry 4.0 technologies. We explore if the use of Industry 4.0 technologies have an impact on allowing CP in NPD or not. All in all, this study aims at understanding whether, or not, firms using more Industry 4.0 technologies allow more CP in NPD stage.

The contribution of our paper is threefold. First, we empirically document adopter firms' perspective on the impact of using Industry 4.0 technologies on CP in product design and production. Results show that the firm which uses more Industry 4.0 technologies are more likely to let customers participate in the design and production process of products. Second, we extend the implications of the CP framework in industry 4.0 territory. Although there is no shortage of studies in innovation and marketing literature on CP in NPD, we demonstrate that Industry 4.0 is not just a technological development, the adoption of technologies is a strategic choice to cater customized demands of customers. Our paper is among the preliminary studies on Industry 4.0, which provide empirical evidence on the strategic facet of Industry 4.0 technologies which is an underexplored area. Finally, we empirically extend the investigation on Industry 4.0 to Italian firms to broaden the scope, implications and generalizability of results as the majority of the previous work is either qualitative or uses German firm's data (e.g., Arnold et al., 2016; Müller et al., 2018).

The remainder of the paper is structured as follows: section 2 consists of a brief literature review of Industry 4.0 and CP and hypotheses development thereof. Section 3 discusses the research design and data analysis. Section 4 explains the empirical model and the results. Section 5 comprises of discussion of results and their implications. Finally, we conclude the paper in section 6 by highlighting the managerial implications and limitations of this work and future research directions.

2. Theoretical Background and Hypotheses Development

2.1. Industry 4.0

The term "Industry 4.0" was first introduced in Germany at 'Hannover Messe 2011', symbolising fourth industrial revolution characterized by the use of modern technologies in the manufacturing process. Industry 4.0 is not an easy concept to define because of the range of technologies and their multidimensional individual and connected applications. BITKOM, The German telecommunications association, has highlighted almost 100 definitions of the concept (Bidet-Mayer, 2016). According to Gilchrist (2016), "Industry 4.0 is essentially a revised approach to manufacturing that makes use of the latest technological inventions and innovations, particularly in merging operational and information and communication technology." Table 1, adapted from Müller et al., (2018), provides definitions of Industry 4.0 in the existing literature and highlights the diverse perspectives and points of impact explored by different scholars over the years. In essence, modern digital technologies, like the Internet of things, Big Data, 3D Printing, augmented and virtual reality, robotics and laser cutting constitute the backbone of the fourth industrial revolution (Bressanelli et al., 2018). Table 2 provides an overview of the most prominent Industry 4.0 technologies.

Industry 4.0 has the aptitude of transforming the nature of products and services offered by the firms (Porter & Heppelmann, 2015). Hence, companies are adopting Industry 4.0 technologies to face challenges like customised products and a batch size of one (Bauernhansl et al., 2014). The motivation behind Industry 4.0 – the sum of various technologies to strategically inspire innovation of current manufacturing industry by blending information, technology and humans – is smart manufacturing (Kang et al., 2016). It has helped firms to be more consumer-centric, and CP has

Table 1

Existing definitions and perspective of Industry 4.0

Author	**Definition**	**Point of Impact**
Kagermann et al. (2013)	"Industrie 4.0 will involve the technical integration of CPS into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services and work organisation."	Value creation, business model
Schmidt et al. (2015)	"Industry 4.0 shall be defined as the embedding of smart products into digital and physical processes. Digital and physical processes interact with each other and across geographical and organizational borders."	Customization, production time
Maynard, (2015)	"'fourth industrial revolution'…. is an approach that focuses on combining technologies such as additive manufacturing, automation, digital services and the Internet of Things, and it is part of a growing movement towards exploiting the convergence between emerging technologies."	Social, environmental and economic aspects
Ivanov et al. (2016)	"Industry 4.0 represents a smart manufacturing networking concept where machines and products interact with each other without human control."	Supply chain
Kang et al. (2016)	"Industry 4.0 or Smart Manufacturing is the fourth industrial revolution. It is a new paradigm and convergence of cutting-edge ICT and manufacturing technologies. It provides ground for making effective and optimized decisions through swifter and more accurate decision-making processes."	Efficiency of decision-making process
Kolberg et al. (2017)	"Industry 4.0 is the vision of smart components and machines which are integrated into a common digital network based on the well-proven internet standards."	Digitized production

Table 2:

Prominent Industry 4.0 Technologies

Authors	**Technology**	**Impact / Function**
Barry Berman, 2012	3D Printing	Production of customized goods and company operations at no or little unsold inventory
Esmaeilian et al., 2016	Additive Manufacturing	Computer-aided design is used as an input to develop parts by putting layers of molten material on each other based on the angles and symmetries of CAD model
Yew et al., 2016 Doshi et al., 2017	Augmented Reality	Helps to visualize the computer graphics of the real environment Real-time operation planning and control, defect diagnoses and recoveries and training concerning products and processes
IFR, 2017 Esmaeilian et al., 2016	Robotics	16% increase in the sale of robots Lower defect rates, reliability and high quality
Al-Fuqaha et al., 2015 Jeschke et al., 2017	Internet of Things	Communication between physical object, information sharing Digital representation of manufacturing infrastructure, processes and products
Lavalleet al., 2011 Babiceanu & Seker, 2016	Big Data	Extract value from a massive volume of information Positive influence on performance, maintenance and product customization

become more accustomed to the possibility of all creative work done by customers (Bogers et al., 2016). These technologies provide high flexibility, makes the production process transparent and enhances capabilities to produce individualized products with high productivity, high quality and low costs (Liu & Xu, 2016). Some companies already have empowered customers to work as innovators where company's role is to provide technical support while customers do all the creative work (Cui & Wu, 2016). Corporate practices have given attention to Industry 4.0, but the theoretical contribution is falling behind (Arnold et al., 2016).

The humans are surrounded in a world of nonhuman resources, and their mutual interaction is inevitable (Bowden, 2015). Enhanced intelligent and digital interaction between human and technologies generates more creational opportunities. While new product development is a function of joining customers' needs and technology (Dougherty, 1992), Industry 4.0 possesses such characteristics where firms can utilize technologies to engage customers, rather than depending solely on the marketing information for NPD process (Ramaswamy & Ozcan, 2018b). Product design and manufacturing process is a noetic task with challenges like customized demand, time pressure and high quality at low costs; better designing techniques and modern smart technologies have helped the cause (Giret et al., 2016).

2.2. Customer Participation in New Product Development

Firms' inclination towards CP in NPD has three reasons (Rossmann et al., 2016). First, the internet has facilitated the creation of new channels of customer-firm interaction. Second, customers have increased connectivity and access to information. Third, modern technologies like 3D printing and web 2.0 have enhanced firms and customers' ability to co-create with ease by enhancing connectivity, flexibility and collaboration (Rossmann et al., 2016; Bacile et al., 2014).

The extant literature has interchangeably used many terms for customer participation, but three most commonly used are coproduction, cocreation and customer participation (Dong & Sivakumar, 2017). Co-production represents customer's collaboration with a firm to produce service; hence according to Vargo and Lusch (2008), co-production has two essential elements i.e., collaboration and co-production. While others have used co-production to denote self-production like the self-assembly of product (Haumann et al., 2015) which is a form of customer production but not a joint production. Vargo and Lusch (2004) introduced the term 'co-creation' to shift the emphasis from production to value creation but extensive confusion and misinterpretation of this term exist in the literature as it is frequently equated with other concepts like 'value creation' and 'co-production'. We use the term "customer participation" (CP) because it is more inclusive and more frequently used in literature (Dong & Sivakumar, 2017). This term has also helped to reduce the confusion created by other concepts and has the capability of predicting both active and passive participation. (Dong & Sivakumar, 2017). Dong (2015, p. 498) perceives CP as "the act of engaging customers in the design and production of products and services." Innovation, which is also recognized as "new product development" (Dong & Sivakumar, 2017) denotes the conception and development of ideas which bring incremental improvement and/or radical newness to currents offerings of firms (Berry et al., 2006).

The different phases of NPD proposed by Chang & Taylor (2016) are ideation stage (idea generation and concept testing), product development stage (development of product design and engineering process) and the launch stage (product launch). Most of the literature on CP considers the construct as a whole, but some studies have also analysed the individual CP activities within each stage (e.g., Morgan et al., 2018). In this article, we focus on individual activities in the product development stage, i.e., product design and engineering (production process) (Chang & Taylor, 2016) because the use of technology is most relevant during product design and production process. Previous literature has also emphasised the importance of engaging customers in the development stage (Coviello & Joseph, 2012).

Companies are using CP as a source of competitive advantage (Vargo & Lusch, 2016) and understanding the factors contributing to new product's success is a vital managerial concern (Mu et al., 2017). One way to lower the risk of product failure is to reduce uncertainty by allowing CP in the process of product innovation (Sawhney et al. 2005) and improving the product-market fit (Poetz & Schreier, 2012). The seminal work of Vargo & Lusch (2004) shows that the earlier marketing view originated from economics and was product-centric. The trend shifted when even a higher number of products were unable to satisfy customers (Prahalad & Ramaswamy, 2004). Receiving customers' feedback through interviews and surveys, the firms started using the collected information in their internal R&D departments to develop final products (See also, Cui & Wu, 2017). The availability of self-service technologies provided an opportunity for customers to participate by serving themselves (Meuter, Bitner, Ostrom, & Brown, 2005) (e.g., check-in transaction at a kiosk, self-service checkout at grocery stores). But "the logic of these exhortations has relied almost exclusively on an economic rationale" (Bendapudi & Leone, 2003) of saving costs by substituting customers for employees. Cui and Wu (2017, p. 66) argue that "the limited influence of customers in CIS [customer involvement as an information source] does not provide as many opportunities as in CIC [customer involvement as co-developers] to ensure that their creative inputs are understood and utilised in NPD.". Now customers have become an integral part of the innovation process and can engage themselves in the product development process by using operant resources like knowledge, physical and mental skills and technology (Vargo & Lusch, 2004; 2017).

2.3. Hypotheses Development

Customer participation in product design

Customers should be allowed to participate in different phases of product development (Carbonell et al., 2009). Product design is a source of competitiveness for firms (Noble & Kumar, 2010; Gemser & Leenders, 2001). By co-designing, customers contribute to the design of product or service (Kohtamäki & Rajala, 2016). Industry 4.0 creates new channels of customer interaction, and such engagement and connectivity are reflected by CP in product design and engineering (Müller et al., 2018). “Technology is as much an operant resource as are human beings” (Ramaswamy & Ozcan, 2018b, p. 203). Industry 4.0 technologies provide firms with more liberty to produce customized products. Courtesy modern technologies like additive manufacturing, 3D scanner and 3D printing, now customers can design and create 3D printed products in industries where customer involvement was previously restricted due to difficulty of acquiring required tools (Bstieler et al., 2018). With customer involvement, a graphical product configuration is generated, and the personalized prototype is developed with the help of additive manufacturing and 3D printers while CAD model helps to optimise the geometric parameters of consequent 3D printing (Zheng et al., 2018).

3D printing is not only a vital component of additive manufacturing but also one of the examples of cyber-physical systems (Li, 2018). Additive manufacturing (AM), 3D scanners, augmented reality (AR) and virtual reality (VR), integrated with cyber-physical system and internet of things, enable the development of porotypes in real-time (Kolarevic, 2003). Customer experience and expectation regarding co-design can be recorded with the help of technologies like virtual reality and augmented reality (Zheng et al., 2018). Firms also use a massive volume of data gathered from customers participation to understand better the customers’ choice and pattern of the shift from existing products to new customised demands. By investing in new technologies, Industry 4.0 reduces the cost of production of personalized products and creates a competitive advantage over the firms perusing mass production (Müller et al., 2018).

The implication of Industry 4.0 technologies provide flexibility in production and enable firms to produce a batch size of one and individualized products (Bauer et al., 2014; Emmrich et al., 2015). The novelty of the idea is not in new technologies but in combining them in new ways (Drath & Horch, 2014). Industry 4.0 technologies operate together in a digitally connected environment to create an interactive manufacturing platform (Ramaswamy & Ozcan, 2018b). We argue that if a company adopts one or fewer technologies which can only develop a digital design of a product or can only develop prototypes will be relatively less inclined towards allowing CP in design. While a company which has more technologies ranging from digital design to the development of finished products will more likely allow CP in design as they are more equipped to provide customers with the final customized product. The individual technologies have their specific use, but when they are used collectively in a connected environment, then companies can generate more possibilities of catering customised demands by engaging customers in the design process. Grounded in this argument, we propose the following

H1. *Among the adopters of Industry 4.0 technologies, the firms which use more of these technologies, allow more customer participation in product design development.*

Customer participation in the production process

Co-designing of products also implies some changing in the roles in the production process of a firm (Moreau & Herd, 2010). Participating as co-designers and collaborative partners, customers are increasingly integrated into the design and production of products and services (Wischmann et al., 2015). The technologies and principles of Industry 4.0 influence the production process of goods (de Sousa Jabbour et al., 2018). The comprehensive interaction between actors is represented by increased customer engagement in product design and engineering process (Müller et al., 2018). Companies strive to ensure that even producing a single product should be profitable for them while the customers want to have the reach to real-time quality data of the production to guarantee that the products will match their desires (Zheng et al., 2018). Industry 4.0 provides actual production status and connective technologies to address the desire of CP in the production process while still safeguarding the profitability of businesses. For example, technologies like augmented reality, additive manufacturing and 3D scanners and printers can project, in advance and during the process, how the manufacturing process is going to unfold, the amount of work done, the remaining time and the quality of work.

In the internet-enabled environment, “mixed-reality interfaces” (augmented and virtual reality) of the digitalized world encourage CP by reducing the distance between actual experience and people (Ramaswamy & Ozcan, 2018a). The automated manufacturing with laser cutting and robotics and supervision with 3D scanners, MR and AR not only safeguards the quality and avoids delays but also ensures customers’ access to live production and quality data at any time (Nee et al., 2012). From mobile devices like smartphones and tablets, the data regarding every critical machine component can be visualized in real-time (Zheng et al., 2018). As Augmented and Virtual Reality can envision the production process, a combination of these digitized technologies and real-time manufacturing data create an effective interaction between machines and users (Zheng et al., 2018).

CP in Industry 4.0 scenario is happening, and companies are ensuring it to make the process transparent. IoT connects different components of the production environment. Enabled by virtual visibility, digital technologies like VR and MR allow end-users to foresee machine data projected on the real section of a machine (Nee et al., 2012). In Industry 4.0, information visibility plays a crucial role in decision making (Zheng et al., 2018). Industry 4.0 can let customers approach the real-time information of the production stage (Müller et al., 2018). Working in a connected environment, we expect a positive impact on the use of more Industry 4.0 technologies on CP in the production process as well. Therefore, we hypothesise,

H2: *Among the adopters of Industry 4.0 technologies, the firms which use more of these technologies, allow more customer participation in the production process of products.*

3. Research Methodology

3.1 Data Collection

We used a structured questionnaire submitted through computer-assisted web interviewing (CAWI) targeting chief operating officers or managers in charge of technological and manufacturing processes. The assistance over the phone was provided to the respondents to help them understand the questions while they filled the questionnaire. The research was conducted on a population of 8,022 firms from the AIDA database, which contains comprehensive information on Italian companies. The firms belong to made in Italy industries of home furnishing, mechanics, fashion and electronics. The geographical location of the firms is Northern Italy (Piedmont, Lombardy, Veneto, Trentino-Alto Adige, Friuli Venezia Giulia, Emilia-Romagna) and was selected because of their importance in international competitiveness and relevance for Italian GDP. Italy provides an ideal case to study the impact and use of Industry 4.0 technologies for two main reasons. First, being a developed country, Italy offers the essential playground for the implementation of modern technologies. Secondly, Italy was reviving from the recession when the idea of Industry 4.0 was introduced, which makes Italy a follower of the trend than an initiator.

The reviving scenario provides some characteristics of developing countries, and hence results of the study are expected to have a broader canvas. The questionnaire was directed to collect data about seven technologies of industry 4.0 namely, (1) 3D scanner, (2) Additive manufacturing, (3) IoT and Intelligent products, (4) Robotics, (5) Big data and cloud, (6) Augmented reality and (7) Laser cutting. The set of modern technologies of industry 4.0 is extensive, but these seven technologies address the strategic requirements of B2B and B2C manufacturing firms better than others (Sander et al., 2016). Data were collected from May to December 2017.

Scholars have different opinions about the maturity of the debate on Industry 4.0. Some consider the field new and prefer to adopt the qualitative and exploratory approach and favour case studies (Müller et al., 2018), the literature review or both (Liao et al., (2017). This study is among the very few who have adopted an empirical approach. The total number of interviewed firms is 1,229, and the final sample useful for analysis was 123 (10% of the interviewed firms). The sample size is comparable with existing empirical studies, e.g., n = 133 in Schmidt et al., (2015).

3.2 Measures

To collect the data and develop a hypothesis, we used the term "customer participation" (CP) instead of co-creation and co-production because CP helps to reduce confusion created by different terms. It also depicts active and passive participation, and it provides the freedom to operationalize the concept as dichotomous (whether the consumer engages or not), ordinal or continuous (varying degree of CP) (Dong & Sivakumar, 2017). Chang and Taylor (2016) consider customer participation measure as continuous or binary.

We have two main dependent variables, i.e., CP in product design and CP in the production process. We consider customer participation as an ordinal variable (Dong & Sivakumar, 2017) and use a 5 point Likert scale to measure individual activities of the product development stage, i.e., CP in design and CP in production. On a 5-point Likert scale, 1 represents ‘not at all’ and 5 ‘very much’. Industry 4.0 is described as a sum of various technologies (Hermann et al., 2016). The

Table: 3
Variable measures and description

Variable	Measure	Type
Dependent variables		
	Has the adoption of the Industry 4.0 technologies;	
CP in Design (CP_DES)	i) brought a more active role of customer participation in design of the products	Likert Scale (1-5)
CP in Production (CP_PROD)	ii) brought a more active role of customer participation in production of products	Likert Scale (1-5)
Independent variable		
Industry 4.0 (I.4.0-TEC)	(1) Scanner 3D, (2) Additive manufacturing, (3) IoT and Intelligent products, (4) Robotics, (5) Big data and cloud, (6) Augmented reality and (7) Laser cutting.	Continuous (1-7)
Control Variables		
Size	Size of the firm measured as the natural logarithm of the number of employees	Continuous
Firm’s location	Location of Companies (at the regional level: Piedmont, Lumbardy, Emilia-Romagna, Trentino Alto Adige, Veneto, Friuli Venezia Giulia).	Dummy
Industry Type	Industry to which a firm belongs	Dummy
R&D	Internal R&D investments (as % on turnover)	Continuous
B2C	1 if company operates in B2C (vs. B2B)	Dummy
Competitive advantage	1 if firm’s competitive advantage is product innovation	Dichotomous
ROA	Avg. of ROA of last 5 years	Continuous

primary independent variable of interest in Industry 4.0 technologies used and represents the count of technologies used by the firm, i.e., 1 represents a firm using one technology and so on until a maximum of 7. Table 3 provides the detail of the measures used for variables and brief description.

We controlled for the size of the firms by taking the natural log of the number of employees (Belderbos et al., 2004) because it is challenging for larger firms to involve customers in their product development process as they tend to have a relatively stable and settled system (Schaarschmidt & Kilian, 2014). And smaller firms are more open and motivated to complement their shortcomings and lack of internal skills through customer involvement. We also control for the internal R&D investments of the firm because firms can learn about customer preferences through R&D and can develop new products. R&D investment is measured by dividing R&D by sales (Cuervo-Cazurra & Un, 2007). The targeted customers of companies are also controlled for, i.e., B2B or B2C. A dummy variable is included to indicate a B2C context. industry type, existing competitive advantages of the firms and location of the firm are also included. Although all the firms belong to the North Italian region, the available facilities and infrastructure for a firm in one geographical location (e.g., high-speed internet) could favour the use of one technology over the other. Hence, the location of the firms was also included as a control variable. The cost-oriented firms adopt Industry 4.0 technologies to increase production efficiency while the firms which are The controls for competitive in product flexibility and innovation are more likely to engage customers in the NPD. Hence the existing competitive advantage of firms was also controlled. The adoption of Industry 4.0 technologies and their integration with the current system require some necessary infrastructure and can be costly. So, firms' financial conditions were also controlled for by using average ROA of last 5 years. Table 4 presents the descriptive statistics and correlations of the study.

Table 4
Descriptive Statistics and Correlations.

		Mean	Std. Dev	1	2	3	4	5	6	7
1	CP_DES	2.64	1.24	1						
2	CP_PROD	2.11	1.10	0.60**	1					
3	I.4.0_TEC	2.43	1.39	0.30**	0.20*	1				
4	SIZE	3.34	1.09	-0.05	0.04	0.34**	1			
5	RD	0.001	0.01	0.14	0.03	-0.08	-0.36	1		
6	B2C	0.37	0.49	-0.16	-0.11	-0.05	0.01	0.001	1	
7	ROA	10161	30029	-0.05	-0.07	-0.04	0.06	-0.10	-0.04	1

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level
Dummies for Industry type, Location and competitive advantage are not reported

4. Empirical Analysis and Results

4.1 Results

OLS regression is used to test the relationships in this study; the impact of Industry 4.0 technologies on CP in both, product design and production process. The results of OLS regression are reported in Table 5. Model 1 and model 3 are only with the control variables while model 2 and model 4 are the full models including the main variable of interest i.e., Industry 4.0 technologies (I.4.0_TEC). Model 1 and model 2 show some interesting results. Size of the firm is significant for CP in product design in model 1 but becomes insignificant in the full model when the Industry 4.0 variable is included. R&D is significant in both, model 1 and 2 while the impact weeker in model 2. H1 predicts a positive impact of the use of Industry 4.0 technologies on CP in product design. The results of model 2 support this hypothesis at $p<0.01$ with the adjusted R^2 of 0.33 which is 0.22 in model 1 run with the control variables only. Model 4 analyses H2, which hypothesises that the use of Industry 4.0 technologies positively impacts CP in the production process of products. We find the empirical support of this hypothesis as well (= 0.28, $p < 0.05$). The adjusted R^2 of model 2 is 0.20 which is way lower in case of only control variables in model 3 (0.13). The results of model 3 and model 4 are quite similar. Apart from the main independent variable of interest, i.e. Industry 4.0 technologies, the results show that internal R&D investments of companies also have a positive impact on increasing CP in design. This result is very interesting as Table 4 does not show any correlation between R&D and CP either in product design or production process. Firms which are competitive in product flexibility are most likely to engage customers in NPD compared to the ones which are competitive in product quality, design and innovation and low cost of production.

4.2 Additional Analysis

Many authors label a specific technology as Industry 4.0. Some Scholars consider IoT, Industry 4.0 (Gilchrist, 2016; Porter & Heppelmann, 2015), others label 3D printing as a new industrial revolution (Berman, 2012). Similarly, numerous articles explore the impact and usefulness of individual technologies like additive manufacturing (Ford & Despeisse, 2016), augmented reality (Yew, Ong, & Nee, 2016) and Big Data (Li et al., 2015) in the new product development process. In an additional analysis, we investigated the impact of individual technologies on CP in design and production process empirically. One of the arguments of the main analysis was that the individual technologies have their specific use while their connected use could open a broader and newer set of opportunities for product development. To validate our claim, we explored the firms' perspective on the use of individual technologies. For this, we replace the variable 'Industry 4.0 technologies (I.4.0_TEC)', with individual technologies; 3D

Table 5
Results of analysis

Variables	Model 1 (Control Variables)		Model 2 (CP_DESIGN Full Model)		Model 3 (Control Variables)		Model 4 (CP_PRODTION Full Model)	
	β	t	β	t	β	t	β	t
(Constant)	1.23	1.52	1.29	1.74	0.92	1.21	0.97	1.34
I.4.0_TEC			0.36***	3.23			0.28**	2.51
Control Variables								
SIZE	0.35**	2.22	0.06	0.34	0.30**	2.07	0.08	0.51
RD	52.68 ***	2.72	41.19**	2.26	24.50	1.34	15.80	0.89
B2C	-0.60	-0.12	0.15	0.52	-0.23	-0.79	-0.07	-0.24
ROA	-0.01	-0.60	-0.01	-0.75	-0.02	-1.05	-0.02	-1.19
Industry Type								
Rubber	-0.49	-0.75	-0.41	-0.69	0.03	0.06	0.09	0.15
Electronics	-0.66	-1.37	-0.68	-1.53	-0.06	-0.13	-0.07	-0.17
Automotive	-1.68***	-3.44	-1.25**	-2.65	-0.75	-1.63	-0.42	-0.92
Jewelry	-0.62	-0.79	-0.53	-0.73	-0.48	-0.65	-0.41	-0.58
Sportswear	1.87	1.53	2.23**	1.96	1.89	1.64	2.16*	1.95
Eyewear	-0.38	-0.73	-0.55	-1.15	-0.83	-1.70	-0.96*	-2.05
Clothing	-0.50	-0.97	-0.29	-0.61	0.22	0.45	0.37	0.80
Textile	-1.82	-2.80	-1.69***	-2.80	-1.02	-1.67	-0.92	-1.57
Leather	0.26	0.41	0.61	1.01	0.72	1.20	0.99	1.69
Firm Location:								
Emilia Romagna	0.40	0.79	0.26	0.55	-0.07	-0.14	-0.17	-0.38
Friuli Venezia Giulia	-0.44	-0.70	0.08	0.13	-0.16	-0.27	0.23	0.40
Lombardia	0.54	1.40	0.40	1.09	0.17	0.47	0.06	0.18
Trentino	1.41**	2.21	1.14*	1.90	0.74	1.23	0.53	0.91
Competitive Advantage								
Product Quality	-0.12	-0.28	-0.05	-0.14	0.36	0.90	0.41	1.08
Product Innovation	0.91	1.64	0.48	0.91	0.88	1.70	0.56	1.09
Product Design	1.11	1.63	0.75	1.17	1.19	1.86	0.91	1.47
Product Flexibility	1.07**	2.31	1.06**	2.49	1.38***	3.17	1.38***	3.31
Cost Reduction	0.56	0.82	0.66	1.04	0.68	1.06	0.76	1.24
Adjusted R^2	0.22		0.33		0.13		0.20	

scanner, additive manufacturing, IoT and intelligent products, robotics, Big Data and cloud, augmented reality and laser cutting in three models and kept all other variables in the analysis. These technologies may not necessarily have the same role in CP in product design and production process. The aim here is to provide a preliminary analysis which surely requires further research to explore the role of these technologies in detail.

Results of this session are provided in Table 6. We test both the models to analyse the impact of individual technologies on CP in product design and production process. Use of augmented reality shows a significant positive impact in both models i.e., CP in design and production process (=1.02, p<.05, =0.81, p<.05). Robotics is insignificant in CP in the production process and additive manufacturing is significant for CP in product design (=0.77, p<.05). Big data shows a minor negative impact on CP in production (= -.47, p < .1) The individual impacts of the use of 3D printing, Laser cutting and IoT by the firms are insignificant.

Table 6
Additional Analysis: Impact of single technologies

Variables	Model 1 CP_DES		Model 2 CP_PROD	
	β	t	β	t
(Constant)	0.52	0.68	0.81	1.09
3D Scanner	-0.29	-0.76	0.45	1.24
Additive Manufacturing	0.77**	2.20	0.16	0.49
Augmented Reality	1.02**	2.67	0.81**	2.18
Robotics	0.59**	2.09	0.28	1.00
Laser cutting	0.41	1.44	0.40	1.47
Big data	-0.39	-1.42	-0.47*	-1.76
IoT	-0.11	-0.21	0.32	0.64
Adjusted R^2	0.41		0.30	

5. Discussion

Our paper aimed to explore the strategic aspect of the adoption of Industrial 4.0 to produce customised products. Instead of focusing on the technical aspect of Industry 4.0 technologies, we used Italian firms' data to empirically document firms' perspective of using these technologies. We hypothesised a positive impact of higher adoption of Industry 4.0 technologies on CP in the product development stage, i.e., CP in product design and production process. The empirical results showed the support for both hypotheses. The strongest and most significant impact of the use of more Industry 4.0 technologies on CP was found during product design. The effect on CP during the production process was relatively smaller and significant at $p < 0.05$. This is logical because during the design development of a new product, the customer inputs are mostly transformed into digital and computer-aided designs. The firms have not yet committed the investments in the production process and the desired changes in computer-aided designs are relatively easier. Once the production process starts, the incorporation of customer inputs is relatively difficult as different elements are connectedly working in the production process and changes in one would lead to changes in the whole process. This leads to a relatively less significant impact of Industry 4.0 technologies on CP in the production process as compared to CP in design. Our paper contributes to the literature on Industry 4.0 technologies and CP in NPD.

First, we empirically documented firms' perspective of using Industry 4.0 technologies to produce customized products, a claim rarely analyzed empirically. The baseline of Industry 4.0 technologies is about revolutionizing the production in an age of digitalized interactions where it is inadequate for grasping new opportunities through the traditional notion of offering a fixed set of features in products and services (Ramaswamy & Ozcan, 2018a). Although some researchers believe that the discipline of Industry 4.0 technologies is immature, and the cases and qualitative studies are more appropriate approaches while others argue that in individuality, the technologies are in use for quite a while now and Industry 4.0 put forward the idea to use them in a connected environment at a larger scale. We believe that the results of our study will provide a new direction to the ongoing discussion in this field.

Secondly, modern technologies are penetrating the manufacturing industry and increasing their capabilities by making them smart, to address the challenges of shrunk time to market and increased customization (Yli-renko & Janakiraman, 2008). Industry 4.0 provides a natural scenario to extend CP in the NDP framework in this territory which we have done in this study. Third, an interesting finding of our paper is that we got the support for H2, which predicted a positive impact of the use of Industry 4.0 technologies on CP in the production process. The existing literature argues that the firms are traditionally reluctant to encounter customers in their production process. Firms have the concerns regarding the spillover of know-how and procedure and especially the deep routed syndrome of "not invented here" (Katz & Allen, 1984), and sometimes customers are not interested to know how the product is produced or they may also lack the awareness regarding the production process (Lukas, Whitwell, & Heide, 2013). Our results provide a stimulating point of debate on studying CP in the production process before the results can be generalised. The phenomenon of CP which started from simple customer feedbacks and evolved as lead users and innovation toolkits have reached the stage where customer can engage with firms and work as co-developers of the products they want.

The type of industry a firm is operating in, the physical location of facilities and the existing competitiveness have a varying approach towards allowing CP in NPD. The sportswear firms were more prone to CP than others. The firms which had a competitive advantage in product flexibility granted more CP in two models. The results from the additional analysis revealed that apart from the apparent nature of Industry technologies, their use is firm-specific. The firms which use Augmented Reality, let customers participate in both, design and production process. Additive manufacturing was significant in product design which shows that the firms are using it mainly for prototype development instead of finished products. The use of Robotics helped to ensure CP mostly in design but not in the production process. The insignificant result of 3D printing is surprising because 3D printing is in use for quite a while now and many leading firms like G.E. are using this technology in technology-intensive industries. Big data showed a negative but relatively smaller impact to on engaging customer in production process and overall CP. The firms could be using Big data to enhance their internal knowledge base and capabilities of R&D department and also that the real-time access to data has created fear of losing customers (Müller et al., 2018). Hence the small firms might be afraid of their shortcomings being highlighted by the customers.

As technologies, physical and virtual components are increasingly digitised and connected, their implication in human value creation is also increasing (Ramaswamy & Ozcan, 2018b). Industry 4.0 is not only a technological change in production, but it also impacts organisational changes and opportunities. As the associated costs and technological barriers have decreased considerably (Saarikko et al., 2017), more and more firms are adopting these modern technologies. The successful implementation requires changes in the business model of the firms as Industry 4.0 technologies are suitable for decentralised information and decision system.

6. Conclusions

Moving away from the technical aspects and highlighting the strategic adoption of Industry 4.0 technologies, this paper shows that when companies use technologies in a connected way, companies are better able to involve customers in designing and producing the products. This study is among the initial research which has adopted an empirical approach to analysing firms' perspective of using Industry 4.0 technologies.

This study has some limitations as well, which provide a way for future research. First, this study uses the data of the firms, which are the adopters of Industry 4.0 technologies and analyse their impact on CP in design and production process. Although this study fills an essential gap of postulating firms' perspective of using these modern technologies but a comparative study between adopting and non-adopting firms regarding their behaviour towards allowing more CP in NPD will be an interesting study. The possible line of action could be to analyse the commonalities between two types of firms and the differences created by the adoption of these modern technologies.

Second, this study aims to analyse the impact of Industry 4.0 technologies on individual activities of the overall customer participation during the product design and production process. We use a single-item measure from the existing literature. Although some studies have adopted such measures, future studies can also target on developing a better measure for CP in design and production process. Third, we documented that the Industry 4.0 technologies work better in a connected environment and a higher number of technologies a firm use, more customer participation is ensured. A modest understanding of this argument can be misleading as the paper does not discuss the most effective combinations of technologies or any specific technology which plays a central role in the connected environment. Results show that the adoption and utility of these technologies are industry-specific, hence a cautious interpretation of results is suggested. We used simple OLS for the analysis, the future studies can use other sophisticated techniques like SEM and case study.

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Adoption of 3D Printing in Makerspaces: Antecedents and Consequences

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Abstract

Traditionally, consumers have played a passive role in the production of the things they use. But the recent advancements in digital technologies like 3D printing (3DP) and their increasing availability especially in makerspaces have empowered individual user commonly known as makers to fabricate their ideas into physical objects digitally. While the potentials of 3DP for end-users are discussed frequently, it is crucial to explore the motives which lead to its adoption, use and implications in terms of innovation performance. This study applies an extended model of the unified theory of acceptance and use of technology 2 (UTAUT2) on a sample of 338 makers, who participated in an online survey and are current users of 3DP, to empirically analyse the drivers of acceptance and use of 3DP by makers. Results show that performance expectancy, social influence, facilitating conditions and hedonic motivation influence makers intention of using 3DP which in turn has a positive impact on the actual use of 3D printing. The empirical findings also confirm the positive effect of the use of 3DP on innovation performance of the makers. The study provides theoretical and practical implications for 3DP manufacturers, makerspaces organisers and managers.

Keywords: 3D printing, makers, makerspaces, maker movement, innovation performance, UTAUT2

1. Introduction

It is a world of work where "workspace" does not represent the factory floor or office building anymore (Barley, 2016). Technological changes and economic volatility have directed more people to work autonomously outside the secure contexts of organizational cultures (Petriglieri et al., 2019). As people experiment with the available tools and technologies, new subjectivities and actors are arising as makers, hackers, fixer, entrepreneurs and innovators in design and fabrication (Smith, 2017). A significant driving force of this spread is the “maker movement” (Gershenfeld, 2012) which represents the individuals working independently. The creation of physical objects is the essence of the maker movement, and a key factor of the maker movement is “makerspaces” (Singh, 2018). Makerspaces are "open access communities for individuals to meet, socialize, exchange ideas and to work on projects related to technology, science and arts" (Halbinger, 2018, p. 2028).

The access to “a digital thread from the raw materials all the way through to the finished product” (Merfeld, 2014, p. 28), like 3D printing (3DP), enables firms as well as individual makers to execute a project from design stage to final output (Rayna & Striukova, 2016a). 3DP is the direct transformation of a digital design into a physical model which reduces the need for tooling. The standard definition of 3DP is “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” (ASTM, 2012). Developed in the 1980s, the early use of 3DP was confined to costly industrial manufacturing applications. This trend altered in the late 2000s when 3DP was taken up by trends like do-it-yourself (DIY), open-source and makers movements (Unruh, 2018). Now, around 14% of the makerspace participants use 3DP in their innovation activities (Halbinger, 2018).

The number of consumer-grade 3D printers, which can cost as less as €1,000, sold in 2013 alone surpassed the total number of industrial 3D printers sold since 1984 (Wohlers, 2014). The research discussing the potential of 3D printing in revolutionizing the manufacturing at the individual level is increasing in size and scope (Anderson, 2012; de Jong & Bruijn, 2013; Kietzmann et al., 2015; Kleer & Piller, 2019; Moilanen & Vadén, 2013; Petersen et al., 2017; Petersen & Pearce, 2017; Rayna & Striukova, 2016a). With all the excitement about 3DP, yet to date, existent literature does not provide noteworthy insights regarding the factors affecting the acceptance and use of 3DP by end-users and the innovative outcome of its use. Recent research shows that makerspaces are very crucial in promoting and using 3DP (Woodson et al., 2019). Hence it is essential to ascertain the motivation for increasing adoption of 3D printers by the visitors of makerspaces, commonly known as makers.

The objective of this study is to explore which factors trigger the acceptance and use of 3DP by makers, and what is the impact of the use of 3DP on their innovation performance. I empirically seek the answer of these questions by applying an integrated model based on the unified theory of acceptance and use of technology 2 (UTAUT2) (Venkatesh et al., 2012) with one additional influencing variable, IT competence and one outcome variable, innovation performance. UTAUT2 is a well-established and frequently used model. Previous studies have demonstrated its usability and flexibility by applying it in different technological scenarios with additional variables (e.g., (Duarte & Pinho, 2019; Halassi et al., 2019; Oliveira et al., 2016)). To use makerspace as the context of this study is important because to enforce the fact that 3DP is not only about printing freely available online designs. Its broader expansion requires that the users should print not only the design of the objects developed by others but also the ones produced by themselves (Mahapatra et al., 2019). Secondly, to make a distinction between the designers who develop the custom variation in designs and the people who simply print them (Mellis, 2012) like in the case of home users of 3DP (Petersen et al., 2017) whereas makers normally create and work on their ideas.

This study contributes to the literature on potentials of 3DP, makers and makerspaces. The empirical findings show that the makers are accepting 3DP as they aspect it to increase their performance. The availability of facilitating conditions, opinion of people around them and the fun factor of using 3DP also influence their intention to use it. Makers' innovation performance is also positively impacted by 3DP use which highlights the 3DP relevance for entrepreneurs. Makerspaces organizers can use these findings to invest in the proper facilities to maximize the use and benefits of 3DP for makers.

Next section consists of a brief overview of the existing literature on makerspaces, 3D printing and UTAUT2 and the hypotheses development. Section 3 explains the research setting, data collection and measurements of the variables used in this study. Empirical findings and results are discussed in section 4. Section 5 discusses the findings of the article in detail. Section 6 concludes the paper by elaborating the theoretical and managerial implications of the results, the limitation of this research and the suggestions for future work.

2. Literature Review and Hypotheses Development

2.1 3D Printing (3DP)

3DP has captivated the attention of populace via platforms like do-it-yourself (DIY), maker movement (Anderson, 2012) and makerspaces (Woodson et al., 2019). 3DP has some exclusive features which distinguish it from other manufacturing technologies and make it suitable for makerspace innovation. Unlike traditional manufacturing method where the material is removed to get the final product, 3DP works on the principle of additive fabrication, i.e., layers of material are added on each other to get the complete shape. This feature favours the diverse group of makers as it eliminates the need for developing expensive and time-consuming tools and significantly reduces product lifecycle costs (Ma et al., 2018). 3DP provides opportunities for freedom of design (Jiang et al., 2017) because unlike tooling, an unlimited number of design iterations can be done on the CAD file. As the material layers bind together directly from a 3D design, it reduces the product development time and intensity of physical flows (Holmström et al., 2017) and eliminates many intermediaries especially labour (Ford & Despeisse, 2016).

3DP is not resource-intensive and is therefore ideal for makerspace settings because unlike big firms, makerspaces and makers do not have abundant financial resources and infrastructure. Some designs are challenging to manufacture because of their complexity. 3D printing facilitates the production of geometrically complex designs which, if developed by using conventional machines, are either impossible or at least very costly (Attaran, 2017). Economies-of-one entails that the production of a single part is possible in a cost-effective manner (Baumers et al., 2016).

2.2 Makerspaces

Makerspaces take several forms like hackerspaces and fab labs (Peeters et al., 2019). Makerspaces have been used as local places of shared resources and provision of manufacturing technologies that are not as commonly available as internet connectivity and computers (Kostakis et al., 2015). Makerspaces have the perception of the sites which can disrupt the existing institutions of production and consumption (Smith, 2017). Conventionally, the innovative products are developed based on rapid prototyping in universities' research centres, R&D departments and in larger firms. Most likely, a small group of experts has access to resources and means needed to develop a prototype in a short time (Anderson, 2012). Makerspaces takeout this liberty of a smaller group and democratize the process and opportunities of innovation.

Digital technologies have enabled individuals in carrying out innovative activities at their initiatives (Rayna & Striukova, 2016a). The advent of technologies like 3D printing is particularly important for makerspaces because it provides individuals (makers) with end to end means of carrying out innovative projects (Petrick & Simpson, 2013; Rayna et al., 2015). Leading scholars in innovation literature expect makerspaces to be a powerful vehicle for boosting consumer innovation (Von Hippel, 2017; de Jong et al., 2015). A reason for the increasing number of makerspaces and amplified interest in their analysis is related to the rise of innovative activities carried out by people working as makers. Participants of makerspaces mostly work on their projects, and at the same, they can also build on the experience and knowledge of others or collaborate with other members to bring about innovation.

2.3 UTAUT2

Technology acceptance is described as "the approval, favorable reception and ongoing use of newly introduced devices and systems" (Arning & Ziefle, 2007, p. 2905). Many theories have been proposed to analyse the factors influencing the intention to accept and use technology. But the researchers face the dilemma of "pick and choose" constructs from different models or merely select a "favored model" (Venkatesh et al., 2003). The UTAUT2 (Venkatesh et al., 2003) provides a solution by integrating eight models, rooted in information systems, psychology, and sociology: the Technology Acceptance Model (TAM), the Theory of Reasoned Action (TRA), the Theory of Planned Behavior (TPB), the combined TAM and TPB model, the motivational model, Innovation Diffusion Theory (IDT), the model of Personal Computer (PC) utilization, Social Cognitive

Theory (SCT). The UTAUT2 (Venkatesh et al., 2012) is the adaptation of UTAUT (Venkatesh et al., 2003) to analyse the acceptance and use of technology in an end-user context.

In UTAUT2, behavioral intention (BI) is defined as a consumer's intention of using technology. The factors influencing the intention to use technology in UTAUT2 are 1) Performance expectancy (PE), defined as the measure of benefits to an individual from the use of a given technology; 2) Facilitating conditions (FC), represent the supporting resources and helping environment for the use of technology; 3) Social influence (SI), is the degree to which a consumer thinks that important people around believe he or she should use a technology; 4) Effort expectancy (EE), the level of effort required to use and complete a task by using a technology; (5) Hedonic motivations (HM), represent the pleasure and joy a person gets from technology usage; Price value (PV), the financial cost of the technology compared to the benefits of using it, and (7) Habit, expressed as consumer's spontaneous act of using technology due to the accumulated learnings over a period of time. UTAUT2 proposes a positive impact of behavioral intention of using technology on the actual use of technology. In UTAUT2, use (USE) is the measures the frequency of actual use of technology. In this study, USE is defined as the use of 3D printing during different stages of project development.

Habit is not considered in the framework of this study. Including habit in the UTAUT2 to directly affect use intention is problematic. Venkatesh et al. (2012) justify the inclusion of habit in UTAUT2 by citing Limayem and colleagues (2007). However, Limayem et al. (2007) claim that habit has a very complex and moderating role in the relationship between actual behavior and behavioral intention. Also, compared to other technologies, 3D printing is not very mature. Hence I do not expect any habitual behavior (Halassi et al., 2019). A new variable, IT competence

(Bassellier et al., 2001) is added in the model as a likely determinant of makers behavioral intention and actual use of 3DP.

I added one more variable, innovation performance (Scott & Bruce, 1994) in the model to explore the impact of 3DP on the innovativeness of makers. UTAUT2 was originally developed and tested for mobile internet. Majority of the studies using this model, in its original form or with some modification, have mostly analysed mobile apps and internet-banking related services. The baseline model of UTAUT2 confers the factors affecting the acceptance and use of technology. An important aspect of the use of technology is the outcome of the use. 3DP is hailed as a central technology of the fourth industrial revolution, famously referred to as Industry 4.0. Unlike other technologies, 3DP has the potential to enable end-users in bypassing the firms altogether in some sectors by designing and fabricating physical object on their own. It's widespread adoption by makers, and other end users can cause severe threats to the profits of companies. Thus, it is also important to probe into the outcomes of the use of 3DP. Therefore, I included 'innovation performance' in the model to analyse the impact of 3DP use on makers overall innovativeness. According to Scott and Bruce (1994), individual innovation performance is the generation and recognition of adopted or novel idea, seek support for its implementation and finally completing the idea by developing a physical prototype of the innovation. 3DP encompasses all these stages from idea generation (in CAD design), to the physical final object; it suits the innovative activities of makers.

Competence at the individual level is usually conceptualized as the potential that leads to efficacious performance (Bassellier et al., 2001). Competency can also be expressed specifically to fit a particular functional area, discipline or job (Kollmann et al., 2009). In the IT domain, Bassellier et al., (2001) define individually possessed competency as IT-related knowledge and experience obtained by and individual which helps him or her in contributing to the technical side of the organization. For makers, I define IT competence as the IT-related knowledge and experience of a maker which helps him or her in using different digital and fabrication technologies in innovation activities. Additive style of manufacturing in 3D Printing de-emphasizes post-fabrication, manual skills, and iteration and places emphasis on expression in 3D modelling and digital skills instead (Mellis, 2012). The know-how and experience of different IT-technologies and application helps makers in understanding and developing CAD models. Familiarity with different information technologies inspires makers to use 3D printing in their innovation activities.

2.5 Hypotheses Development

In this section, the reasoning of the proposed hypotheses is given. Based on the stated goals, figure 1 presents the proposed model for this study.

Performance Expectancy

Performance expectancy refers to the ability of a new system or technology to help users accomplish what they want more productively and creatively (Venkatesh et al., 2003). In this study, performance expectancy is defined as the degree to which a maker believes that using 3DP helps him or her in developing an innovative outcome, i.e., product or project. Previous studies in other technological scenarios have established that performance expectancy is a strong driver of the behavioral intention of using technology. Hence the following is articulated:

H1: Performance expectancy is related to makers' intention to use 3DP.

Effort Expectancy

Effort expectancy in UTAUT2 originates from Davis' (1989) perceived ease of use who describes it as the ease of use in executing some activities. It captures an individual's perception of the necessary effort to complete a task using technology (Venkatesh et al., 2003). For 3DP, it is the measure of the ease of use of 3DP by makers during different stages of the development of their projects. Following Venkatesh et al., (2003, 2012), I expect a positive effect of effort expectancy on the intention to use 3DP:

H2: Effort expectancy is related to a makers' intention of using 3D printing.

Social Influence

Social influence is the extent to which social environment motivates and influences a user in adopting a technology (Moore & Benbasat, 1991; Thompson et al., 1991; Venkatesh et al., 2012). It is a strong positive influencer of intention to use technology (Venkatesh et al., 2003). Makers usually work on their projects (Halbinger, 2018), and their innovations are mostly known to themselves or the maker communities around them. As makers work in a closely connected environment with other makers and their core motivation of carrying innovation activities is the betterment of their self or the people around them, I expect a positive impact of social influence on the behavior intention to use of 3DP.

H3: Social influence is related to makers' intention to use 3D printing.

Facilitating Conditions

Facilitating conditions delineates a person's impression about the availability and accessibility of essential resources to use a technology (Brown & Venkatesh, 2005; Taylor & Todd, 1995). 3DP is not only a vital component of additive manufacturing but also one of the examples of cyber-physical systems (Li, 2018). A computer-aided design (CAD) file is developed on a computer to optimize the geometric parameters by using software (Zheng et al., 2018). All these components should be interlinked and compatible with each other. The effective use of 3D printing would not be possible without such infrastructure of supportive and facilitating conditions. Availability of such facilities favors the intention to use and the actual use (Venkatesh et al., 2012) of 3DP. Accordingly, I propose the following hypotheses:

H4: Facilitating conditions are related to makers' intention to use 3D printing.

H5: Facilitating conditions are related to makers' use of 3D printing.

Hedonic Motivation

One of the antecedents of behavioral intention of using a technology incorporated in UTAUT2, originally not present in UTAUT, is hedonic motivation. Along with performance expectancy (extrinsic motivation), intrinsic motivation is considered an important driver of customers' intention to use new applications and systems (Alalwan, 2018; Wamba et al., 2017). Hedonic motivation can be conceptually expressed in terms of intrinsic motivation (pleasure, enjoyment, fun, playfulness) that can arise from the use of new technologies (Venkatesh et al., 2012). By nature, 3D printing is an interactive and engaging technology, and I expect a positive impact of the hedonic motivation on the behavioral intention to use 3D printing among makers;

H6: Hedonic motivation is related to the behavioral intention of maker to use 3D printing.

Price Value

When extending UTAUT to a consumer context, Venkatesh et al. (2012) added the construct 'price value' in UTAUT2. PV is defined as "the consumers' cognitive trade-off between the perceived benefits of the applications and the monetary cost for using them" (Venkatesh et al., 2012, p. 161). The use of 3DP is not resource-intensive, eliminates intermediaries like labour and tooling and reduces the time and cost of product development. These features increase the weights of compared to the cost of a 3DP. Hence it is expected that the price value of 3DP will positively affect makers' intention to use it.

H7: Price value is related to makers' behavioral intention to use 3D printing

Use of 3DP

Apart from the acceptance, the other aim of UTAUT2 is to predict the use of technology. Venkatesh et al., (2012) and Venkatesh et al., (2003) express use in terms of frequency of usage of technology. For the use of 3D printing by makers in this study, use is defined as the use of 3D printing during different stage of project development like idea generation, product development and product completion. The underlying theory of all the intention models discussed by Venkatesh et al., (2003) to develop the UTAUT predicted a positive impact of the behavioral intention on the use of technology and the relationship is frequently tested in other technologies studied and supported in both, organizational and consumer settings. I also hypothesize the same for 3D printing;

H8: The behavioral intention of makers is related to their use of 3D printing.

IT Competency

To 3D print freely available online digital design may be as easy as it sounds, but makers do not just want to print existing designs. They are more interested in developing new ideas and physically fabricate them. For 3DP to reach broader acceptance, users should print not only the design of the objects generated by others but also the ones developed by themselves (Mahapatra et al., 2019). The digital file of the 3D-printed object comprises of all the required data to fabricate that object. No additional skills or information is required other than the access to an appropriate

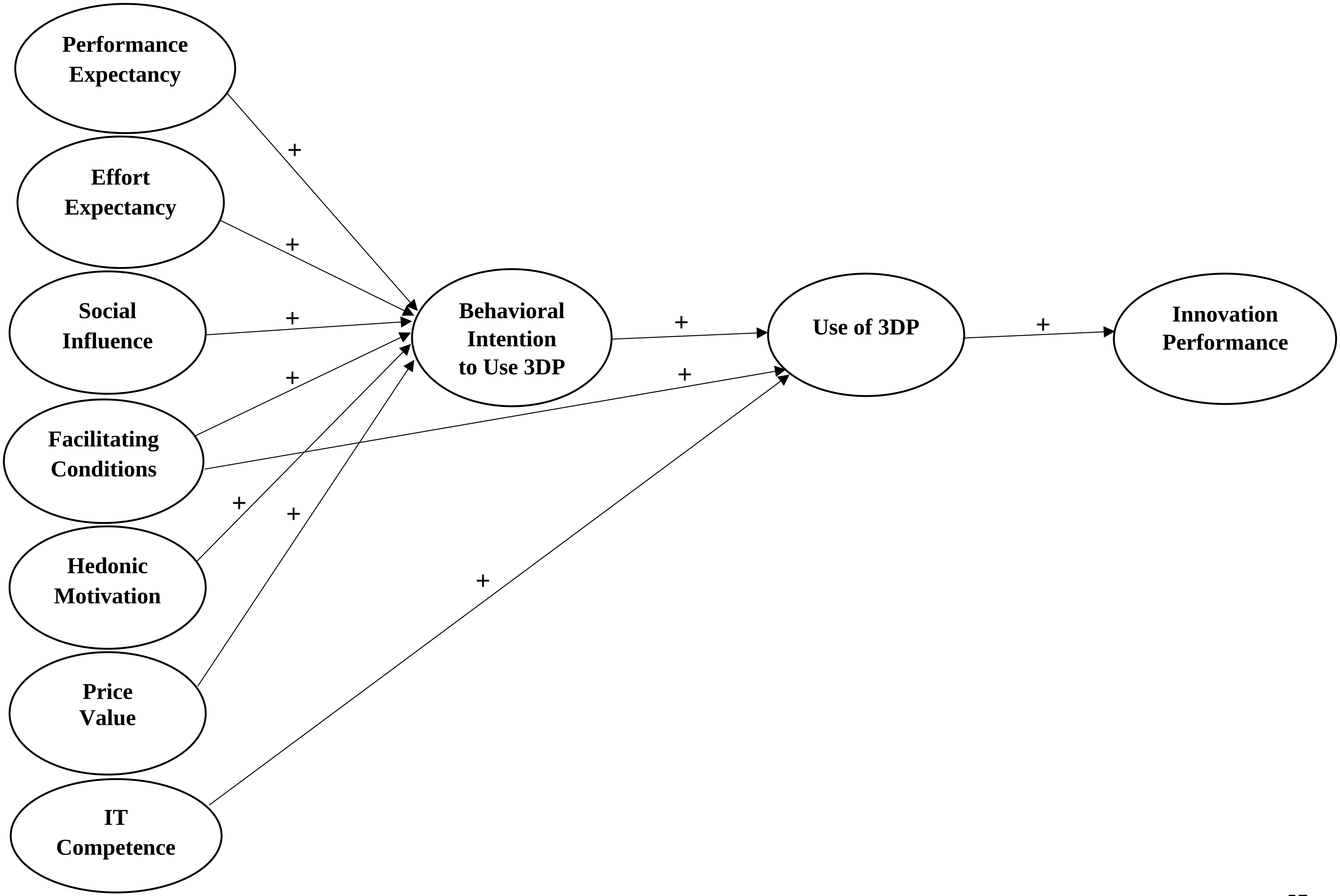

Fig 1: Research Model

3DP machine for fabrication. While 3DP makes the fabrication and assemblage of complex parts easy, it increases the skills necessary to develop 3D modelling of such items. IT-competence is not essentially linked to a precise task, but rather relates to the ability to transfer knowledge across tasks (Bassellier et al., 2001). Example of IT competence includes expertise in hardware, software and knowledge of IT applications useful in daily routine work. IT know-how and experience will have a positive influence on intention to use and actual use of 3DP as it can help realize complex and multi-functional products by using 3D printing. Therefore,

H9: IT-literacy is related to the use and use of 3D printing by makers.

Innovation performance

Until recently, user content generation was predominantly considered an online phenomenon (Dahlander & Frederiksen, 2012; Rayna & Striukova, 2016b). Now with the advent, decreasing cost and increasing availability of digital technologies like 3D printing, the same is happening in the "offline" physical world (Rayna & Striukova, 2016b) like makerspaces. The definition of individual innovation performance by Scott and Bruce (1994) divides it into three main parts; idea generation or recognition, either adopted or novel, search for support to implement the innovative idea and the physical prototype of the innovative idea. Product development also has three broader stages; idea generation, development phase and completion phase. 3D printing is not only relevant in all three stages but also very practical and effective for makers. During the idea generation phase, maker develops the CAD model of their idea which contains all the information of the physical object. In development and completion of physical object, 3D printers receive the command from the digital file and transform the information in the form of material layers upon layers. Maker may not have funds and support from outside to develop the physical object, 3D printers serves this purpose well to develop and complete the physical fabrication. Hence, I propose;

H10: The use of 3D printing is related to the innovation performance of makers.

3. Research Methodology

To empirically test the proposed research model (fig. 1), a self-administered online survey questionnaire was used. Conducting a survey study on makerspace participants require careful consideration of formats and distribution channels (Hielscher & Smith, 2014). The survey was sent only to the participants of those makerspaces which were currently offering 3D printing facility to their visitors.

3.1 Data Collection

The sample for the survey was collected from the makerspaces registered at three platforms; hackerspaces.org, makerspaces.make.co and fabfoundattion.org. These platforms provide basic information about the facilities provided by makerspaces. I collected the email addresses of those makerspaces which have 3D printers at their facilities. Initially, I collected 931 emails address of makerspaces with a 3D printer. After removing the double entries and the inactive webpages, the sample size was reduced to 791.

The makerspaces registered on these three platforms use different terms to represent them, i.e., makerspace, hackerspace and fab-lab. To understand the impact of the sensitivity of the various terms used for their identity on responses and to make sure if the respondents interpret the wording of the questionnaire, a pilot study was conducted by using only the term 'makerspace', and the survey was sent to randomly selected twenty-five email addresses from each platform. Eighteen responses were received; eight from hackerspaces, six from makerspaces and four from fab-labs. None of the respondents showed any concern of the term 'makerspace' and no significant differences were found in the demographic profile. (From this point forward, I only use the term "makerspace" for all platforms for the sake of simplicity).

These 75 email addresses were not used in the final analyses. The survey was sent to remaining 716 email addresses. 42 emails bounced back from invalid addresses and from the people who were not, anymore, affiliated with the makerspaces. Nineteen respondents requested a translated version of the questionnaire; three respondents were displeased of being called makerspaces as they described themselves as hackerspaces, and one such case was reported for makerspaces as well. Seven makerspaces were not using 3D printing anymore. All these cases were removed, and the final contacted sample was reduced to 644. 355 individual responses were received, of which 19 were rejected due to incomplete responses. Hence, the final sample consisted of 338 valid responses. The problem of social desirability bias was addressed in different ways (Podsakoff et al., 2003). I followed different guidelines in survey design. To control for the respondents that generally tend to agree with the questionnaire statements than disagree, I used positively worded and negatively worded statements. It is also worth mentioning that the survey did not use the word "innovation" in any question to avoid social desirability bias. Rather, the term "hack" was used to represent innovative developments (product and project, new to the makers or the maker community). The previous research shows that this expression is well known in the maker community and is deemed neutral without any negative connotations (Halbinger, 2018). By using self-reports, I followed the consumer innovation survey approach that identified and conceptualized innovation based on the respondent's perception (de Jong et al., 2015; Halbinger, 2018).

3.2 Participants

A total of 338 makers participated in the survey, and the majority of them was educated, males. Almost 20% of the respondents were females and 80 % male. 39.9% of the total sample fell under the age range of 25 to 34 years, 27% were 35-44 years old, and almost 26% were older than 45 years. None of the respondents was under 18 years of age, while 6.5% aged between

Table 1
Demographic profile of respondents (N = 338)

Demographic profile	Number of Respondents	Percentage
Gender		
Female	70	20.7
Male	268	79.3
Age (years)		
Less than 18 years	-	-
18-24	22	6.5
25-34	135	39.9
35-44	92	27.2
45-54	51	15.1
55 and above	38	11.2
Education		
Less than high school	1	0.3
High school	17	5.0
College	52	15.4
Bachelors	114	33.7
Masters	115	34
PhD	39	11.5
Employment Status		
Employed	220	65.1
Unemployed	49	14.5
Entrepreneur	54	16.0
Student	15	4.4
3DP experience		
Less than 1 year	39	11.5
2 years	48	14.2
3 years	56	16.6
4 years	45	13.3
5 years	40	11.8
More than 5 years	110	32.5
Cost of 3D printer used		
Less than €1,000	146	43.2
€1,000-€5000	156	46.2
€5,000-€10,000	18	5.3
€10,000-€20,000	8	2.4
More than €20,000	10	3.0

18 to 24 years. A majority in the sample was well educated and full time employed. 67.7% had a bachelors or master-level education, and just over 65% were fully employed. 54 out of 338 respondents categorized themselves as entrepreneurs. 32.5% of the sample had more than 5

years of experience of using 3DP. 146 makers were using a 3D printer costing less than €1,000 while the cost of the 3D printers of another 156 makers was between €1,000-€5000. These two groups made up nearly 90% of the total respondents. Table 1 shows the complete demographic profile of the sample group.

3.3 Variables and Measures

For all the variables of UTAUT2 except use, I adapted the measures developed by Venkatesh et al. (2012) with slight modifications for makers and makerspaces context. UTAUT2 measures the use of technology in terms of the frequency of usage. Usually, innovative development comprises of three stages: idea generation, development and launch or completion phase. Following the Candi and Beltagui (2018), makers were asked the extent to which they use 3DP during different stages of their innovation activities. Eight items were adapted from Bassellier et al. (2003) to operationalize IT competence and six items were taken and adapted from Scott and Bruce (1994) for innovation performance of makers. Appendix A reports all the measurement items used in this study. Although all theoretical constructs of this study were operationalized using previously validated scales, slight modifications were made in the wording to adjust the items to a makerspace scenario.

I also controlled for age, gender, employment status and experience of using 3D printing. 50 makerspaces were randomly selected and checked for their inauguration dates. Most of them came into being in or after 2013. Therefore, I set the range of 3DP experience from less than one year to more than five years. Complete detail and the measures for control variables are given in Table 1.

4. Data Analysis and Results

The following section contains the detail of the measurement model and the structural model of structural equation modelling (SEM) linking the variables of this study.

4.1 The Measurement Model

To build the measurement model, the first step was the exploratory factor analysis (EFA) to measure the validity and reliability of the scales. Apart from the UTAUT2 variables except use of 3D printing, the scales of the remaining variables of this study; use of 3D printing (Candi & Beltagui, 2018), IT competence (Bassellier et al., 2001) and innovation performance (Scott & Bruce, 1994) were originally developed and used for managers and organizational contexts. The unit of analysis of this study is the individuals working as makers. Although the scales were taken from the previous studies, the goal of performing an EFA before directly going for confirmatory factor analysis (CFA) was to validate the scale for the makers and makerspaces scenario. Hence, I conducted an initial principle component-based exploratory factor analysis (EFA). One factor emerged for each set of items, and only one item for innovation performance (IP6) was deleted due to low loading value. By repeating EFA on remaining items, the expected 10 factors emerged with Eigenvalues greater than 1 and explained 71.4% of the total variance in the data. The KMO and Bartlett's test for sample adequacy measure provided a value of 0.88, which was above the threshold of 0.8. Hence the adequacy of the sample for the proposed model of this study was also confirmed.

Before testing the hypotheses, confirmatory factor analysis (CFA) was performed to assess the model-fit indices, validity and reliability of the measurement items. There is no established consensus on reporting fit-indices. Thus, various statistics are jointly reported (Klein, 2015). The CFA model showed good fit for the model estimations: $\chi 2/df = 1.75$, RMSEA = 0.047, SRMR = 0.057, CFI = 0.94, TLI = 0.93.

The reliability is defined as the degree of consistency of a measure and the value of the coefficient, Cronbach's α is generally used to test the reliability of scale items. To analyse the internal consistency of items, I calculated Cronbach's α for each variable. The reliability values ranged from .76 to .92, which were greater than the threshold of .70 and indicated a high degree of internal consistency of the scales (Chin, 1998). Based on the value, one item of facilitating conditions (FC4) was eliminated to increase the α of the overall scale. Table 2 contains the full details on the loading values, average variance extracted (AVE), composite reliability and Cronbach's α.

According to Hair et al., (2017), the values of the factor loadings must be greater than .70, and the value of average variance extracted (AVC) should not be less than .50 to evaluate the convergent reliability of the constructs. The results of the analysis revealed that item loading ranged from .61 to .96, and the AVC values were also above the threshold of .50 (Table 2). Initially, the AVE of innovation performance was less than 0.5. After removing one item (IP5), which showed a relatively smaller loading value in CFA, the AVE of the construct improved considerably above the threshold of 0.5. Almost all the indicators except PE4, IT1, IT2, BI2, IP1, IP4 (Table 2) have the loading values greater than .70. Following the recommendations of Hair et al., (2016), I removed these indicators and carefully examined the effect on their composite reliability and content validity. I decided to keep these indicators to maintain the constructs' content validity because the removal of these items did not result in a considerable increase in the composite reliability. The commonly used threshold for the value of composite reliability (CR) is .70 (Fornell & Larcker, 1981). This condition was also met by all ten constructs of this study.

Table 3 reports the correlation matrix and the squared roots of AVE values. The bold values on the diagonal in *italics* are the squared roots of AVE while the numbers below the diagonal demonstrate correlations between main variables of interest. The correlation matrix

Table 2: Factor Loadings and Convergent Reliability

	Loadings[a]	AVE[b]	CR[c]	CA[d]
Performance Expectancy (PE)				
PE1	0.77			
PE2	0.86	.58	.85	.84
PE3	0.72			
PE4	0.69			
Effort Expectancy (EE)				
EE1	0.84			
EE2	0.88	.66	.88	.88
EE3	0.78			
EE4	0.73			
Social Influence (SI)				
SI1	0.79			
SI2	0.96	.80	.92	.92
SI3	0.93			
Facilitating Conditions (FC)				
FC1	0.71			
FC2	0.74	.52	.76	.76
FC3	0.71			
Hedonic Motivation (HM)				
HM1	0.96			
HM2	0.80	.74	.89	.89
HM3	0.80			
Price Value (PV)				
PV1	0.78			
PV2	0.76	.65	.85	.84
PV3	0.86			
IT Competence (IT)				
IT1	0.61			
IT2	0.65			
IT3	0.70			
IT4	0.77			
IT5	0.71	.54	.90	.91
IT6	0.87			
IT7	0.84			
IT8	0.72			
Behavioral Intention (BI)				
BI1	0.80			
BI2	0.69	.62	.83	.81
BI3	0.87			

Use of 3DP (USE)				
USE1	0.77			
USE2	0.85	.62	.83	.82
USE 3	0.73			
Innovation Performance (IP)				
IP1	0.67			
IP2	0.84	.52	.81	.83
IP3	0.73			
IP4	0.62			

[a] Loadings = factors loadings, [b] AVE = average variance extracted, [c] CR = composite reliability, [d] CA = Cronbach's α

is useful both from a methodological and substantive point of view. From a substantive point of view, the correlation matrix provides initial insights into the relationship between the variables of interest. Regarding its methodological importance, the low values of correlations between different constructs support the claims of discriminant validity of measures. Additionally, the squared root of AVE value of each corresponding construct was greater than its highest correlation with any other construct. This measure is known as the Fornell-Larcker criterion (Fornell & Larcker, 1981). The underlying logic of this method is that a variable of interest shares more variance with its indicators than with other variables. All the correlations between constructs are below the most commonly used threshold of .70 (Dormann et al., 2013). The highest correlation of .59 along with the highest VIF of 2.02 is taken together to confirm that multicollinearity is not a concern in this study. The Fornell-Larcker criterion is most commonly used method for checking discriminant validity, but a new method has also emerged and gained popularity: the heterotrait-monotrait (HTMT) ratio of correlations (Henseler et al., 2015). The HTMT was also calculated to prevent the issues of multicollinearity issue, and all the value were below the required 0.85 threshold.

I applied different methodological remedies in survey design to control for common method bias (Podsakoff et al., 2003) like the use of positive and negative wording and avoiding the normative wording like “innovation performance”. Apart from that, I also performed post hoc analysis for common method bias by conducting Harmon's single factor test and common latent factor test (Podsakoff et al., 2003). The one-factor model explained a variance of 26.5% which is considerably lower the threshold of 50%. The common latent factor test in CFA showed that the commonly shared variance among all items was less than 19%. Based on these analyses, it can be concluded that common method bias is not a problem in this study.

Table 3: Descriptive Statistics, Correlations and Discriminant Validity - Fornell-Larcker criterion

	Mean	SD	PE	EE	SI	FC	HM	PV	IT	BI	USE	IP
PE	5.81	1.02	***0.76***									
EE	5.70	1.10	0.36**	***0.81***								
SI	3.44	1.66	0.28**	0.13*	***0.89***							
FC	6.23	0.79	0.41**	0.46**	0.07	***0.72***						
HM	5.93	1.14	0.57**	0.34**	0.21**	0.31**	***0.86***					
PV	5.35	1.15	0.30**	0.20**	0.09	0.29**	0.38**	***0.80***				
IT	4.11	0.71	0.15**	0.20**	0.01	0.30**	0.14*	0.15**	***0.74***			
BI	5.97	1.03	0.58**	0.39**	0.24**	0.49**	0.56**	0.29**	0.18**	***0.79***		
USE	4.07	0.84	0.51**	0.31**	0.31**	0.36**	0.40**	0.20**	0.21**	0.46**	***0.79***	
IP	3.69	0.88	0.25**	0.9**	0.22**	0.37**	0.20**	0.24**	0.39**	0.33**	0.36**	***0.72***

** = $p < .01$, * = $p < .05$

Note: PE = Performance expectancy, EE = Effort expectancy, SI = Social influence, HM = Hedonic motivation, PV = Price value, IT = IT competence, BI = Behavioral Intention, USE = use of 3DP, IP = Innovation performance

4.2 The Structural Model

After testing the measurement model, the structural model was tested during the second stage of SEM to verify the conceptual model and proposed hypotheses. The fitness of the structural equation model must be evaluated before assessing the path coefficients for hypothesis testing. Overall goodness of fit for structural model resulted in CMIN/df = 1.75, CFI = .93, TLI = .92 RMSEA = .047 and SRMSEA = .063. All the fit indices meet the acceptable fit levels of RMSEA ≤ .08, CFI ≥ .90, TLI ≥ .90 and SMIN/DF ≤ 2 (Hair et al., 2010; Tabachnick & Fidell, 2007).

I assessed the path coefficients of research hypotheses and their significance by using bootstrapping with 10,000 resamples. The results are reported in table 4. Seven out of ten hypotheses were supported. With respect to the factors affecting the maker's intention to use 3D printing, the result showed that makers intension to use 3DP is significantly predicted by PE (H1) (β = 0.27, p = 0.003), SI (H3) (β = 0.05, p = 0.039), FC (H4) (β = 0.54, p = 0.000) and HM (H6) (β = 0.34, p = 0.000). Contrary to the original model of UTAUT2, effort expectancy (H2) and price value (H7) showed an insignificant impact on intention to use 3D printing by makers.

Table 4: Effects on Endogenous Variables

	Estimates	Standard Error	*p*
H1: PE→BI	0.27	0.09	0.003
H2: EE→BI	-0.003	0.08	0.996
H3: SI→BI	0.05	0.03	0.039
H4: FC→BI	0.54	0.12	0.000
H5: FC→USE	-0.60	0.14	0.530
H6: HM→BI	0.34	0.09	0.000
H7: PV→BI	-0.47	0.06	0.340
H8: IT→USE	0.14	0.08	0.049
H9: BI→USE	0.42	0.11	0.000
H10: USE→IP	0.34	0.08	0.000
[a] Control Variables		YES	

Note: PE = Performance expectancy, EE = Effort expectancy, SI = Social influence, HM = Hedonic motivation, PV = Price value, IT = IT competence, BI = Behavioral Intention, USE = use of 3DP, IP = Innovation performance

[a] Gender, Age, Experience of using 3DP and Employment status (employed, unemployed, entrepreneur or student) were added for 'Use' and 'Innovation Performance'.

Hypotheses H5, H8 and H9 predicted a positive impact of FC, BI and IT competence on the USE of 3DP respectively. H8 predicting the positive effect of intention to use 3DP on its actual use by makers was supported (β = 0.42, p = 0.000). Contrary to original prediction, no empirical support was found for facilitating conditions' impact on makers use of 3DP (H5). The newly introduced antecedent of USE, IT competence also had a positive impact on actual use of 3DP by makers (H9) ($\beta = 0.14$, $p = 0.049$). To analyse the effect of the use of 3D printing on the innovation performance of makers (H10), I introduced a new construct in the UTAUT2 model i.e., IP and found the empirical supported for the hypothesized positive influence of the USE of 3DP on IP of maker ($\beta = 0.34$, $p = 0.000$).

Controls variables; gender, age, 3DP experience and employment status were also included in the model for the use of 3D printing and innovation performance. The experience of using 3D printing showed the significance for both use of 3D printing and innovation performance. Apart from this, young males and entrepreneurs were more likely to use 3D printing.

5. Discussion

3D printing is hailed as a central technology to drive the fourth industrial revolution but most of the existing research on 3D printing is theoretical. The literature lacks empirical evidence, especially at the individual level, regarding the factors influencing the acceptance and use of 3D printing.

In line with the UTAUT2 model, makers' intention to use 3D printing is positively influenced by PE (H1), anticipation of increase in their performance; SI (H3), referral of 3D printing from important others around them; FC (H4), the availability of the supporting facilities to use 3D printing and HM (H6), the pleasure and joy from using 3D printing. Consistent with previous studies (Halassi et al., 2019), the strongest predictor of makers' behavioral intention to use 3DP was facilitating conditions (H4). Proper use of 3D printing requires other essential resources as well. This result implies that makers do not just use 3DP to print existing freely available designs; rather they are more interested in creating their innovative ideas and use 3DP to physically fabricate them. For that, a CAD (computer-aided design) file is developed by using a software, a computer system and internet connection. For 3D printing to be functional and useful, the availability of such supporting facilities becomes very crucial.

The impact of hedonic motivation (conceptualized as intrinsic feelings like pleasure, joy and entertainment) on makers' behavioral intention of using 3DP was also empirically supported (H6) as it appeared as the second most persuasive factor. Majority of the participants of makerspaces consider their innovation activities as self-rewarding (Halbinger, 2018) i.e., payoff based on personal use, helping others, learning and enjoyment (Von Hippel, 2017). In other words, makers are encouraged to use 3DP with the increasing level of hedonic motivation existing in the use of such technology.

The performance expectancy (H1) relationship finding is consistent with previous studies in other technological scenarios (Duarte & Pinho, 2019; Oliveira et al., 2016). Makers work on innovative ideas which are important and new for them and/or for the community around and commercializing their innovations is not their prime motives (Halbinger, 2018). In such a situation, the performance expectancy of using technology becomes very crucial. Makers expect 3D printing to increase their performance as it reduces many intermediaries and shortens the development time which in turn positively impacts their intention to use 3D printing. Social influence also demonstrated a relatively smaller but positive impact on makers' intention to use 3DP (H3). Socializing and exchanging ideas is an important feature of makerspaces. In a social environment like this, it is expected that social influence can play an influential role over the intention of makers as people take in great account of social stimuli and substantial referents (Choi & Geistfeld, 2004).

On the contrary, the results did not confirm the significance of two factors of UTAUT2 model, namely, effort expectancy and price value on makers' behavioral intention to use 3D printing. One possible explanation of these conflicting results could be that the makers are self-motivated and work on the innovative ideas which they find useful for themselves and the community around them. The usefulness of 3DP in completing their project could be more important than the effort required to learn and use 3DP. Hence the effort expectancy was insignificant as the effort expectancy decreases as with the increase in perceived usefulness of technology (Davis, 1989). One reason for insignificant impact of price value on intension can be that 3D printers are available in makerspaces and makers pay a nominal subscription fee to visit makerspaces and use the facilities available there. As makers do not necessarily have to buy a 3D printer for themselves, price value is not important for them. Other studies have also found insignificant results for effort expectancy and price value on behavioral intension (Baptista & Oliveira, 2015).

In UTAUT2, Venkatesh et al. (2012) defined ‘use’ as the frequency of the usage of technology. For this study, it is defined as the use of 3DP during different stage of innovative project development like idea generation, product development and product launch or completion for one’s self or the community around them. For the results regarding the actual use of 3DP by makers in makerspaces, hypotheses H5, H8 and H9 were respectively developed to predict a positive influence of facilitating conditions, intension to use and IT competence on the actual use of 3DP by makers. As conceptualized in UTAUT2, actual use of technology is influenced by the behavioral intension. The positive impact of intension on use demonstrated in this study (H8) is in line with previous research. The behavioral intension (BI) had the most substantial effect on the use and overall, it was the second strongest factor in the proposed model. IT competence was a newly added construct in the UTAUT2 model as an antecedent of 3DP use by makers (H9) and the relationship was empirically supported. The 3DP process has eliminated the constraints of traditional manufacturing methods. Different software tools can be used to design forms for digital fabrication by using 3DP. Still, the CAD file of the printable object should be in line with the capabilities of the 3D printer to achieve maximal benefits. Printing with different material and newer techniques are complicated, and skills are required for 3DP process planning to achieve desired cost, properties and appearance (Dwivedi et al., 2017). A pre-hand knowledge and experience of different ICT technologies can be helpful in effectively using 3DP for ideation and fabrication of objects.

H5 predicting the positive influence of facilitating condition on actual use was not supported. The result shows that facilitating condition affected the intension behavior but no significant effect of facilitating conditions was found on the actual use. The result is similar to other recent work (Macedo, 2017). A likely explaining for such results is that for 3D printing, the availability of supporting facilities like a computer, an internet connection and a supporting software package might be important to induce makers in using 3D printing. Once makers start using 3DP, the importance of such facilities decreases, and they are not perceived as necessary because such facilities are considered generally available.

The study went further and made a vital addition in the model to analyse an important but never empirically tested aspect of the 3DP usage, the consequence of use of 3DP by end-users i.e., the impact of 3DP use on innovation performance of makers (H10). I found the support for the hypothesis which proposed a positive impact of 3DP use on innovation performance of makers. Anderson (2012) advocates the potential of 3DP for individuals but the literature lacks the empirical evidence of such claims. As makers work in makerspaces with limited resources, 3DP suits their style of work. To the best of my knowledge, this study is among the very first empirical pieces of evidence of the effectiveness of 3DP for innovation performance at individual-level.

6. Conclusion

The potential of the use of 3D printing for end-user innovation is discussed frequently but never empirically tested. To fill this gap, this research develops and examines a unique theoretical model using the unified theory of acceptance and use of technology 2 (UTAUT2) of Venkatesh et al. (2012) and adding a new construct, IT competence, as an antecedent of the use of 3D printing. To analyse a critical aspect of the use, the outcome of the use, a new construct 'innovation performance' is added in the model to explore the consequences of makers' use of 3DP in makerspaces. This study examines the factors affecting the acceptance and use of 3D printing at individual-level in a makerspace context by using empirical data collected from the makers who are the current users of 3DP. The results show that makers' intension of using 3DP is influenced by performance expectancy, social influence, facilitating conditions and hedonic motivation and behavioral intension then also has a positive impact on makers' actual use of 3DP. Moreover, the newly added antecedent of use, IT competence also appears significant. The study also makes an important contribution by empirically testing the impact of 3DP use on makers' innovation performance as the relationship provides significant empirical evidence. The results extend and direct the discussion on 3DP from just printing the exiting designs to innovating and producing physical object.

Three resources namely social exchange, knowledge creation and using technology form the basis of a relationship of makers movement with entrepreneurship (Browder et al., 2019). 3DP is around for a while now and its increasing adoption by makerspaces and positive impact on innovation performance of makers might be the initial signs of a more significant change for end-user innovation. Traditionally, the corporations have controlled the production side of innovation but with 3DP, things can take a different route of bypassing the firms altogether. Still, the future of 3DP remains unclear in terms of their spread at the household level, especially in the presence of makerspaces and other 3DP platforms offered by manufacturers.

3D printing is the direct conversion of digital design into physical objects with an additive style of manufacturing. The increasing quality at decreasing costs of 3D printers has enabled end-user and makers to innovate on their own and print the products of their choices. Innovating by using 3DP, the user communities like makers can extensively compete with corporate innovations and possibly displace them all together in many sectors of the economy (de Jong & Bruijn, 2013). But the factors affecting the acceptance and use of 3D printing (3DP) by makers has been scarcely studied. Additionally, no worth mentioning empirical evidence is available on the impact of the use of 3DP on innovation performance at an individual level. Hence, this research offers important theoretical implications for existing research on 3DP.

First, this study extends the UTAUT2 (Venkatesh et al., 2012) to 3DP context, which is a relatively different technology. Early studies have mostly used the UTAUT2 model in mobile apps (Duarte & Pinho, 2019) and e-banking and mobile payment contexts (Baptista & Oliveira, 2015; Oliveira et al., 2016; N. Singh et al., 2020) which share a lot of commonalities. 3DP is different in a way that it has both the software and hardware aspects. The results show that makers' intention to use 3DP is influenced by performance expectancy, social influence, facilitating conditions and hedonic motivation and the intention to use also has a significant effect on the actual use. Although some of the proposed relationships are not supported, i.e., the influence of effort expectancy and price value on intension to use, these findings assert the overall predicting power of UTAUT2 for 3DP as well. A new antecedent of the use of 3DP, IT competence was introduced in the model which was also found significant for the use.

Second valuable contribution of this study is the empirical evidence of the use of 3DP on makers' innovation performance. "Bursts of innovation happen when an emerging technology removes a once prohibitive barrier of cost, distance, or time" (Lipson & Kurman, 2013, p. 59). Most of the makerspaces provide their participants and visitors with 3DP facilities (Moilanen, 2012; Lindtner et al., 2014). As 3DP eliminates the need for intermediaries like tooling and labor, it coincides well with makers style of work. A closer look at the pattern of results indicates that on one side makers' intension of using 3DP is influenced by factors like performance expectancy, social influence, facilitating conditions and hedonic motivation while effort expectancy and price value are insignificant. It indicates that makers primary use 3DP because they enjoy using it as they expect superior performance in the presence of required facilitating conditions and feedback from important people around them. The insignificance of effort expectancy hints that makers' primary motive is the effective realization of their ideas into physical objects. As long as 3DP is helping them achieve their goals in a fun a pleasant way, they are indifferent about the required effort to learn and use 3DP.

Despite the growing importance, very little research is available on the maker movement, and the management literature has very scattered mentions of it (Browder et al., 2019). This study also makes important contribution to the growing literature on makerspaces, which are a critical component of maker movement (S. P. Singh, 2018), and highlights the importance of 3DP for makerspaces and makers. Home or consumer-grade 3D printer costs less than a thousand euros while the price of professional-grade 3D printer is around 2,500 euros (Rayna & Striukova, 2016a). Trends have suggested that 3D printing is going to be a big deal as the industry is expected to be worth $ 6 billion by 2019 (Kietzmann et al., 2015). Although the existing research shows the potential of 3DP for home users (Petersen & Pearce, 2017), makerspaces are the ones playing a critical role in spreading 3DP to a broader audience working on their own ideas (Woodson et al., 2019). The empirical evidence of this study confirms the relevance and usefulness of 3DP for makerspaces and makers in terms of their performance expectancy and innovation performance.

The empirical evidence of this study also has implications from a managerial perspective. First, the organizers of makerspaces can utilize the findings of this research in different ways. For example, 3DP is very important and relevant technology for makers and is a must-have facility in a makerspace. More importantly, facilitating condition is the strongest predictor of intention to use 3DP. 3DP will be beneficial only if the supporting facilities are also available. Free of cost workshops can also be arranged for visitors of makerspaces to demonstrate the fun and entertaining ways of using 3DP as hedonic motivation was another important factor alongside social influence which influenced makers intention to use 3DP. Informative sessions about different information technologies could also be arranged to provide basic knowledge and awareness. The manufacturers of 3D printers can use the insights of this study to incorporate the relevant features into their future models of 3D printers. Makers expect the experience of using 3DP to be joyful alongside an increase in their performance and a positive impact on their innovation performance. The print quality and print development rate are crucial features in this regard.

Sharing is central to makerspaces and the maker movement. The design and physical objects created and shared by the makers can also create unwanted copyrights and piracy issues. For instance, there are more than 50,000 open-source designs available in the Thingiverse database, one of many design depositories, which can provide a starting point of an innovative or customized design. The similarity in features can also cause damage to brand reputation. Although it will not be practically possible to counter the issue of piracy at such a broad level, still it is an important aspect the legislators and the companies must keep in their consideration.

This study did not include any firm-level construct yet there are some key insights for the manufacturers. Combining the significant results of performance expectancy, innovation performance and relatively higher use by the entrepreneurs (used as a control variable) hints a plausible to the profits of manufacturing firms. Though, a cautious explanation is required to claim the generalizability of this result as the number of entrepreneurs was only 54. Still, the companies should keep a closer look at the trends of 3DP adoption by end-users and try to adopt affective methods to engage customers in their product development processes to meet their customized demands. The spread of 3DP at the household level remains unclear in the presence of makerspaces. Additionally, big firms like Shapeways and Oceanz, generally known as supercenter (Sasson & Johnson, 2016) provide the printing facilities on a wide range of 3D printers in terms of size and quality. As this study provides preliminary evidence of the impact of 3DP on makers' innovation performance, policymakers can dedicate funds for the spread and availability of subsidized and higher-quality 3D printers in makerspaces to usher user innovation.

This research is not exempt from limitations. Several important questions remain unanswered, requiring further examination and additional research. One limiting factor of this research is the probable concern of sample representativeness. The questionnaire was sent to the email address of makerspaces which was then further distributed to the makers who were using 3D printers. Although the sample size of this study is reasonable, the information about the true universe of 3DP users could not be confirmed due to primitive empirical research at individual-level. Future research can replicate this research with the well-developed databases to check the generalizability of results. This study made an important empirical contribution to the factors affecting the intention and use of 3DP and its impact on innovation performance of makers. The result might have been influenced by makerspace-specific characteristics.

Further research can consider different features of makerspaces which can influence makers' 3DP adoption and use decision. This study used a unique cross-sectional dataset to analyse the makers' innovation performance as a result of using 3DP. Hence the problem of reverse causality cannot be completely ruled out. Future research can use an experimental design approach to test the relationship between 3DP and innovation performance. Moreover, one of the objectives of this study was to provide a new direction to the on-going debate on 3DP. Therefore, to avoid the further complexity of the model, no additional variables were considered between 3DP use and innovation performance. Future research can explore the factors which mediate and moderate this relationship in detail.

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Appendix A

Variables and Measures

Performance Expectancy (Venkatesh et a., 2012)	
PE1	I find 3DP useful
PE2	Using 3DP helps me accomplish things more quickly
PE3	Using 3DP helps to increase my productivity
PE4	Using 3DP increases my chances of achieving things which are important to me
Effort Expectancy (Venkatesh et a., 2012)	
EE1	Learning to use 3DP is easy for me
EE2	My interaction with 3DP is clear and understandable
EE3	I find 3DP easy to use
EE4	It is easy for me to become skillful at using 3DP
Social Influence (Venkatesh et a., 2012)	
SI1	People who are important to me think that I should use 3DP
SI2	People who influence my behavior think that I should use 3DP
SI3	People whose opinions I value prefer that I use 3DP
Facilitating Condition (Venkatesh et a., 2012)	
FC1	I have the resources necessary to use 3DP
FC2	I have the knowledge necessary to use 3DP
FC3	3DP is compatible with other technologies I use
FC4	I can get help from others when I have difficulties using 3DP
Hedonic Motivation (Venkatesh et a., 2012)	
HM1	Using 3DP is fun
HM2	Using 3DP is enjoyable
HM3	Using 3DP is entertaining
Price Value (Venkatesh et a., 2012)	
PV1	3DP is reasonably priced
PV2	3DP is good value for the money
PV3	At the current price, 3DP provides a good value
Behavioral Intension (Venkatesh et a., 2012)	
BI1	I intend to continue using 3DP in future
BI2	I will always try to use 3DP in my work
BI3	I plan to continue to use 3DP frequently
IT Competence (adapted from Bassellier et al., (2001))	
IT1	I have valuable knowledge and experience regarding different information technologies (e.g., personal computer, LAN, multimedia)
IT2	I have valuable knowledge and experience regarding different IT applications (e.g., email, ERP, e-commerce)
IT3	I have valuable knowledge and experience regarding different software
IT4	I have valuable experience regarding different system development methodologies (e.g., prototyping, acquisition of software packages)
IT5	I have valuable knowledge and experience regarding different project development practices (e.g., scheduling and budgeting)
IT6	I have valuable knowledge and experience regarding the vision and goal setting for the use of IT for myself
IT7	I have valuable knowledge and experience regarding resource allocation and performance monitoring of the use of IT for myself

IT8	I know how/where to acquire additional valuable information regarding the information systems or IT practices
USE (Candi & Beltagui, 2019)	
USE1	I use 3DP during idea generation phase
USE2	I use 3DP during development phase
USE3	I use 3DP during launch phase (completing the hack for yourself (or) introducing it in the maker community)
Innovation Performance (Scott & Bruce, 1994)	
IP1	I search out new technologies, processes, techniques, and hack ideas
IP2	I generate creative hacks
IP3	I promote and champion hacks to others
IP4	I explore and secure funds needed to implement new hacks
IP5	I develop adequate plans and schedules for implementing new hacks
IP6	I am an innovative person

Thesis Conclusion

All in all, this PhD dissertation consists of two chapters which focus and extend the debate on customer participation in the new product development process of a firm and the innovation performance of the end-users. With the advent of modern technologies, customers have not only become active co-developers by interacting with firms but also the makers of their products. Overall, both studies contribute to the literature by empirically investigating the emerging field of Industry 4.0 and the widespread adoption of 3D printing, especially at the individual level. The dissertation consists of two chapters discussing the relevance and importance of technology in engaging customers in firms' product development process and end-user innovation. The significantly discussed Industry 4.0 technologies are analyzed in general and 3D printing in particular. The first chapter is a firm-level analysis which covers the discussion about the use of Industry 4.0 technologies by firms in product development by engaging customers as co-developers. The argument moves to a specific technology, 3D printing, to explore the factors affecting its acceptance and use by individual innovators and the impact on their innovation performance thereof.

In the first paper, the discussion is taken away from the technological aspects of Industry 4.0 technologies, and the emphasis is put on strategic adoption. More specifically, customer participation in a new product developed is empirically explored from an Industry 4.0 perspective. It is argued that the technologies of Industry 4.0 are interactive. On one end, there are technology-specific features and independent uses while their combined use increases firms' ability to engage customers in their product development stage which consists of product design and production process. The data collected through an online survey conducted on North Italian 'Made in Italy' firms belonging to different industries of home furnishing, mechanics, fashion and electronics. Empirical results confirm the hypothesized relationships that the technologies of Industry 4.0 do have a positive impact on customer participation in product design and production process.

In the second chapter, the discussion is moved from firm-level to individual level. The focus of the second chapter is 3D printing (3DP) to fill the gap of missing empirical evidence of the factors affecting the acceptance and use of 3DP at the individual level. 3DP is different from other technologies in a that the makers can not only make the computer-aided designs of their innovative ideas, but they can also convert that idea into a physical object by using a 3D printer which is easily available. The context of the study is makerspaces which are a key driving force of maker movement and are playing a key role in the adoption and use by individuals working on their projects as makers. I use an extended model of the unified theory of acceptance and use technology 2 (UTAUT2) to test the proposed model. Like first paper, an online survey is used to collect data from 338 makers visiting the makerspaces which have 3DP facilities. The result shows that makers intention of using 3DP is positively influenced by their expectation of an increase in their performance, recommendation by important people around them (social influence), the availability of supporting facilities and the intrinsic feelings of joy, fun and enjoyment (hedonic motivation). The intention of using 3DP and knowledge of different information technologies have a positive impact on the actual use which further has a positive impact on innovation performance of makers. This empirical work offers a very initial empirical of its kind which will help to strengthen the claims of 3DP’s potentials for end-user innovation.

Summing up the contribution of this thesis at the firm-level, the emphasis is to highlight the importance of customer participation (CP) for firms. The phenomenon of CP is unavoidable for firms (Morgan et al., 218); a process which started as the role of customer involvement as a source of information is now an essential part of the product development process (Cui & Wu, 2016; 2017). The adoption of modern technologies of Industry 4.0 is useful to help this cause. The feedback and the discussion of virtual communities of customers (Nambisan, 2002) have now directly connected with the firms in real-time and during the product design and production process. The results of the first chapter put the potential of Industry 4.0 technologies into the spotlight on one end but also leave an answered question for further discussion; the changes in the business models and the training of human resource before the adoption and realization of benefits of these technologies. The technological changes are more frequent than ever before and to maintain the competitive advantage for firms is even more difficult. The firms can get insights from the results of the first chapter to see the relevance of Industry 4.0 in customer engagement but first, conduct an internal analysis to examine the availability of required infrastructure to adopt such technologies.

The results of the second chapter are the portrayal of the importance of technology like 3D printing (3DP) for end-user innovation and the possible impact on the independence of entrepreneur from firms influence. The concept of open innovation and user innovation has been discussed frequently both in literature and popular press (Anderson, 2012; Von Hippel, 2017). More recently, 3DP is being associated, and rightly so, with end-user innovation. The individual working as makers and have innovative ideas can convert them into physical objects by using an increasingly available technology like 3DP. On one end, the industry scale 3D printers are expensive for many firms while on the other hand, their consumer-grade versions are in direct access to end-users. The evolution of customer participation from working as co-developers with firms (Cui & Wu, 2016) and using product-specific innovation toolkits provided to independent makers is happening. The pace of the change might not be so visible, but it is happening courtesy technologies like 3DP. Firms should keep a close look at the adoption pattern of such technology and prepare themselves to compete against independent customers working as makers and challenging firms' offerings and profitability. As these finding show, the customers can not only make products only for themselves, they also compete with firm by carrying out independent entrepreneurial activities.