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3D printing: Making an innovative technology widely accessible through makerspaces and outsourced services

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ABSTRACT

This paper looks into the emerging trends of makerspaces and outsourced 3D printing services, and examines the natural progression between them. Also, by presenting survey empirical data, it investigates the reasons why individual users and enterprises have started to choose such services and the benefits acquired from this choice, that lead to the promotion of creativity, innovation, and competition. Fundamental working principles both for makerspaces and outsourced 3D printing services are being analyzed. Through the conduction of a survey among two different makerspaces' users, authors attempt to further clarify the factors that motivate users to choose to participate in makerspaces or use the services offered by an outsourced 3D printing provider. 3D printing technologies have been recognized as being the new industrial revolution. However, because of the nature of the additive manufacturing process, a high level of expertise is required in order to accomplish an acceptable result. The recent proliferation of makerspaces as well as outsourced 3D printing services offers alternative solutions towards overcoming the aforementioned challenges. Makerspaces are currently growing rapidly, aiming to help local communities to get accustomed with emerging manufacturing technologies such as 3D printing, especially in modern STEM educational practices. On the other hand, outsourcing has emerged as one of the top business practices of our time due to its numerous benefits for the companies involved. The paper makes a comparison between makerspaces and outsourced services and presents relevant original survey data from users.

1. Introduction

The challenging conditions of the 21st century markets require the constant evolution of currently existing products. Ranging from innovative small to medium-sized enterprises (SMEs) to vast multinational companies, there is a constant struggle to offer the best product range based on consumers' needs. The discovery of new raw materials, the introduction of new manufacturing methods and the continuous effort for research and development of new products set a highly competitive commercial environment that evolves in a prodigious pace. Thus, the need for minimizing product development time stands stronger than ever. However, the traditional methods of industrial prototyping cannot always keep up with the demanding time standards set by companies eager to gain a time advantage over their competitors. Prototypes were and, in some cases, still are made from traditional materials like wood or clay. This practice, is time and material consuming. In addition, these kinds of prototypes served mostly as visual aids and could not always stand as functional prototypes. As a tool to

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help overcome the limitations of traditional prototype fabrication, in the late eighties, a new manufacturing method was introduced ([29] Kostakis and Papachristou, 2014). This fabrication technique has to do with the automated fabrication of three-dimensional solid objects sourced from a digital Computer-Aided Design (CAD) file. This was made possible by using additive manufacturing processes in which the deposition of successive material layers on top of each other leads to the final fabrication of the pre-determined three-dimensional physical object. Each successive layer comprises a sliced horizontal section of the final object. Additive manufacturing methods give designers the ability to design 3D objects and fabricate them in their office swiftly and cheaply. In this way, designers have the competence to rapidly examine their design in physical form. Therefore, they can evaluate their design and can conduct the necessary modifications that will lead to the ideal product. Teachers have also started to integrate 3D printing technologies as a part of a complete STEAM (Science, Technology, Engineering, Arts and Mathematics) educational program (Kostakis and [29] Papachristou, 2014, Kostakis et.al.,[30] 2015). 3D printers help towards inspiring a new generation of students trained in STEAM practices by employing problem-solving skills and combining them with creativity and innovation. In addition, such innovative technology also features strong potential to support the educational process in all disciplines. Students learn better through using interaction with such technologies, applied innovation and by doing more than studying books or attending lectures. Therefore, 3D printers exhibit a great way to develop experiential-based learning and expose students to experiences featuring greater degree of practicality. By employing 3D printers, teachers are in a position to offer activities inspired from academic concepts. I.e., in the case of biology classes, students are in position to create a graspable model of a human heart. This type of active learning also ensures that students assimilate and embrace information more easily. 3D printers offer the ability to transform the learning process so that students can be more participatory by solving real problems. In this way, by creating graspable items, students can easily detect potential mistakes, discuss them with the rest of the class and perform necessary corrections. Being described as "the new industrial revolution" 3D printing can, in most cases, be viewed as an end-product fabrication technique as well. Over the years, it was applied in various fields like aerospace, medical sciences, energy, automotive and consumer goods production. Its impact continues to grow due to its ever-deeper penetration in the aforementioned fields, and it is seeing a continuously growing number of people using it worldwide. Some predict that, in the future, we could see a 3D printer in almost every household of the developed world in the next decade (Kostakis and [29] Papachristou, 2014, Kostakis et.al.,[31] 2015). The predicted growth of the already flourishing AM markets is staggering, with predictions becoming constantly more optimistic. The global 3D printing market size is estimated to reach USD 35.38 billion by 2027, according to a report by Grand View Research, Inc. It is predicted to see an average Compound Annual Growth Rate (CAGR) of 14.6% over this specific forecast period ([2] "3D Printing Market Worth $35.38 Billion By 2027" [Online]). The CAGR of the global 3D printing services market from 2017 to 2021, can be found in Fig. 1 categorized by each specific type of material. During this period, the market share for plastic 3D printing is forecasted to grow at an average rate of 24.6 percent per year ("[3] 3D printing services market compound annual growth rate (CAGR) worldwide from 2017 to 2021, by material type," [Online]). The main reasons for this growth are new and improved 3D printing technologies, the introduction of new materials, government funding, constantly expanding application fields and an increased awareness of the 3D printing advantages over traditional manufacturing techniques. Just in the field of worldwide 3D printing market size regarding healthcare, for example, it was valued at $973 million in 2018, and is believed to be $3,692 million by 2026, elevating at a CAGR rate of 18.2% from 2019 to 2026 ("[1] 3D Printing Healthcare Market Outlook – 2026," [Online]).

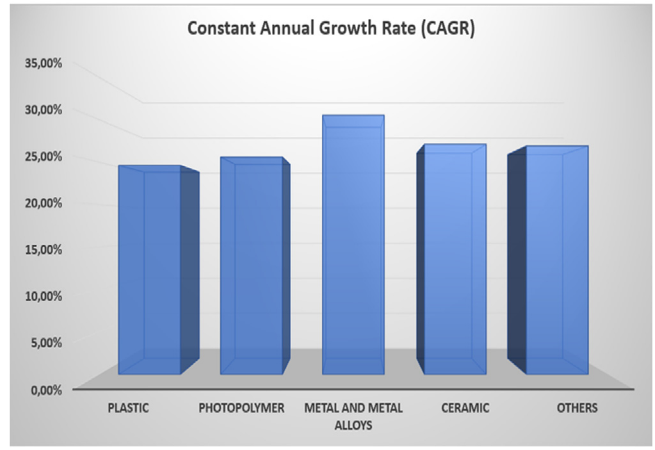

Fig. 1. 3D printing services market compound annual growth rate (CAGR) worldwide from 2017 to 2021, by material type.

1.1. Processes and Fundamental working principles

The basic working principle in every additive fabrication method is the deposition of bulk material in a two-dimensional layer. The third dimension (axis z) comes from the stacking of the deposited layers on top of each other. In the context of this paper, however, it is important to make a distinction between desktop 3D printing and industrial additive manufacturing. Wohlers Report defines desktop 3D printers as those costing less than $5000 ([57] Wohlers, 2019). In contrast industrial machines can cost up to several million dollars. As technologies advanced there have been machines that might cost between $5000 and $50000 that are often referred to as prosumer machines. Ultimately, what differentiates industrial printers is their ability to manufacture production quality parts that can be sold to the customer. The majority of 3D printers used in makerspaces and Fab Labs are desktop printers. The vast majority of these are material extrusion printers, also known as Fused Deposition Modeling (FDM) printers which work on a principal similar to that of a hot glue-gun in which molten polymer material is extruded by moving a hot nozzle on a three dimensional axis, and each layer is printed by extruding the melted polymer material from the hot nozzle to drawing each layer. In the last few years, we have also started to see low cost vat photopolymerization, also known as stereolithography (SLA) systems becoming available in makerspaces. These printers use liquid photosensitive resin as raw material which is subsequently photopolymerized by a guided laser source at pre-determined spots. Thus, 3-dimensional solid objects of high accuracy (higher than FDM) occur.

2. Related work

Researchers in (Rogers *et.al*, 2016) conducted a survey with 404 European firms from different countries, related to the 3D printing industry. The authors in ([45] Rogers *et.al*, 2016), mainly focused on 3D printing as service, detailing the process of how this service works. They introduced three different categories of 3D printing services, which are generative services, facilitative services and selective services. According to their results, 3D printing is an evolving industry with many potentials for future growth during the next decade. In ([11] Beltagui *et.al*, 2021) the authors study the use of makerspaces as an alternative option to 3D printing as a service. The authors point out that this approach, promotes a more hand to hand collaboration between end users of 3D printing and the makerspaces expert will lead to better and more innovating products, as the experts can provide useful feedback. An example of such a makerspace called "iMakerSpace", is described as a case study in ([19] Fidan *et.al*, 2021). According to ([19] Fidan *et.al*, 2021), their accomplishments include but not limited to the development of various innovative services and products. For example, they offer Computer Aided Design (CAD) workshops and 3D printing workshops. A number of open sources products have resulted from makerspaces. Researchers in ([25] Guadagno *et.al*, 2021), developed a 3D-Printable Planetary Roller Screw for Food Processing Applications which is an open source technology for agriculture. Researchers In ([43] Ravindran *et.al.,* 2019) developed an Open Source Waste Plastic Granulator. Its costs less than 2000 USD and it is appropriate for use within maker spaces, fab labs and small businesses. Researchers in ([46] Savonen *et.al.,* 2018) developed a resilient 3D printer for humanitarian crisis response. The researchers proposed a modular machinery, with low cost, commercially available parts as a response to humanitarian situations. The machine is capable of producing vast number of orthopedic devices, therapy tools and replacement parts of medical machinery. Our work differs from the existing literature as it compares makerspaces and fab labs against 3D printing services and it includes an extensive user experience survey with the 3D printing end users.

3. Makerspaces and Fab Labs

A makerspace can be viewed as a collaborative work space featuring an umbrella of actions such as making, learning, exploring and sharing by employing high-tech to no-tech tools. Such spaces exhibit an open-door policy and are addressed to hobbyists, students, kids, adults, and entrepreneurs. They typically, offer a maker equipment-mix ranging from 3D printers, cnc router machines, laser cutters, soldering irons, even sewing machines. In general, such spaces are being created in order to offer entrepreneurs a low-cost working space focused on designing and building prototypes. In a more educational context, makerspaces are the ideal places in which students can first get in touch with the general design and technology education. In addition, they are considered as primary centers of community-driven innovation, where stakeholders such as governments and corporations can meet potential problem-solvers ([48] Stacey, 2014). Participants, in some cases, pay minimal fees that contribute to the makerspace's sustainability while, in most cases, these low fees are combined with financial funds through government funding, private donors, or other sources, as well as staff voluntary work ([36] Pauceanu and Dempere, 2018).An important steppingstone for the creation of such spaces was the rise of the so called "Maker Movement" ([53] Timpson, 2018) which attracted increased scientific attention in the early 2000 s. The maker movement is driven by a "maker culture" exhibiting a more technology-focused progress of DIY culture that mixed with the general hacker culture focuses on creating new physical objects as well as improving the existing ones. Closely supporting open-source hardware, the maker culture favors the use of automated-electronics, 3-D printing technologies, robotics and CNC tools, while simultaneously promoting more classic activities such as physically working with metal, wood and textiles. The creation of physical objects by utilizing such techniques is encouraged by the open-design movement which involves the development of physical objects, machinery and systems by using publicly shared design information ([38] Pearce *et.al.,* 2012, [33] Martinez, and Stager, 2013).A Fab Lab is a makerspace using the trademark name first coined by the MIT's Center for Bits and Atoms. The term "Fab Lab" is an abbreviation of the words "fabrication" and "laboratory". It is used to describe a physical space equipped with easy to use but advanced equipment, where users can get accustomed and utilize the equipment aiming to make "almost anything" ([20] Gershenfeld, 2005). The first Fab Lab was founded at M.I.T. by Prof Gershenfeld in 2001 ([10] Angrisani *et. al.,* 2020). Fab Labs arose as an educational content extension project initiated by MIT's Center for Bits and Atoms (CBA), where combined digital manufacturing and computing research was conducted ([16] Center for Bits and Atoms, "Fab Lab FAQ," Massachusetts Institute of Technology. [Online]). In the following years, a worldwide Fab Lab network was born, promoted by MIT's mother node. A thorough list of every official Fab Labs can be viewed at the website "FabLabs.io". From March 2020, a number of 1890 Fab Labs exist globally covering more than 30 countries ("[5] Fab Lab information." [Online]). A fab lab facility is depicted in Fig. 2. Fab Labs feature an open-door policy to a wide range of individuals promoting a combination of educational, entrepreneurial and research activities. In this spirit, they offer a core set of activities, Fab Labs pursue the combination of entrepreneurial innovation, research, and education in the same physical space ([8] Alia *et.al.,* 2019). Thus, projects initiated on a specific Fab Lab have the potential to be shared, evolved and continued in other Fab Lab facilities. In this way, projects can be shared among the Fab Lab network in a way that different level participants can join them in any Fab Lab globally ([8] Alia *et.al.,* 2019).This Fab Labs network aims to make a societal contribution in various levels (" [4] Fab Lab foundation web ideal lab layout." [Online]). This kind of support cannot be offered by a single Fab Lab, regardless of its scale of capabilities ("[5] Fab Lab information." [Online]). The projects and various designs developed in a Fab Lab can benefit from intellectual protection in terms of a potential patent, but in most cases, it is preferred to make them available to others so that users can use and evolve them ("[6] Fab Lab inventory." [Online]). The open-source and highly collaborative "modus operandi" that Fab Labs feature, is exactly based on encouraging such tactics ([34] Mikhak, *et al.*, 2002).This process is made possible due to the fact that each lab registered to the network is encouraged to share a more or less common inventory. This may include, but is not be limited to, rapid prototyping equipment, typically 3D printers of plastic parts, three axis CNC machines and printing of circuit boards. In addition, microcontroller and sensor kits for designing, assembling, and testing of microelectronics' projects are part of the facility's equipment mix along with sheet material cutters such as laser cutters, vinyl cutters, etc. ("[6] Fab Lab inventory." [Online]). This combination of equipment is suggested by the official Fab Lab network; however, it is quite common for each individual Fab Lab to differentiate a bit to meet the exclusive needs

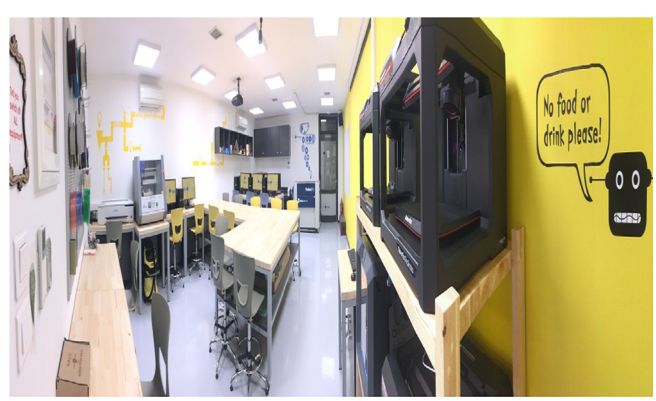

Fig. 2. Fab lab facility.

of the communities that utilize its tools and resources tactics ([34] Mikhak, *et al.*, 2002). Such differentiation is not meant to be discouraged and it is considered desirable tactics ([34] Mikhak, *et al.*, 2002). Fab Labs have formed a global community ([47] Schneider and Lösch, 2019), that, in many ways, has the ability of changing innovation landscapes with social and environmental impact. They have shown a high potential for collective innovation and manufacturing, especially via the utilization of their 3D printing equipment ([47] Schneider and Lösch, 2019). The so called "design global-manufacture local" model is one of high value for local communities and developing countries ([34] Mikhak, *et al.*, 2002, [35] OECD, 2017, [31] Kostakis, *et.al.,* 2015, [32] Mandavilli, 2006, [37] Pearce, *et al.,* 2010). The greatest benefit for developing countries is empowering start-ups or small businesses with little capital to start manufacturing on small scale, then reuse the earnings to finance expansion into mass manufacturing ([34] Mikhak, *et al.*, 2002, [27] Ishengoma and Mtaho, 2014). In terms of sustainability and environmental, Fab Labs have formed a Green Fab Lab Network, that promotes projects emphasizing in open source symbiotic economy and circular economy ([14] Byard, et.al. 2019, [56] Troxler, 2011, [50] Stefanakis, Jones and Nikolaou, 2021, [49] Stefanakis and Nikolaou, 2021). Such Fab Labs use raw materials derived from local recycled plastic streams obtained at local level. The ability of printing in more than one material offer huge material energy and time savings for these spaces ([56] Troxler, 2011).

3.1. Makerspaces and 3D printing

Makerspaces can be characterized as collaborative spaces for digital fabrication since 3D printers are a vital ingredient of a mix of equipment. Makerspaces aim to perform as places that spread the digital manufacturing know-how to interested individuals and, in this way, be highly conducive in promoting 3D printing, due to the fact that such spaces are linked with this activity ([56] Troxler, 2011). On the other hand, digital fabrication in the form of 3D printing, has not yet reached individual users in a similar way that personal computers have, notwithstanding all the hype around the current availability of low cost/affordable 3D printing. However, the access to low level and advanced 3D printing equipment offered by makerspaces and maker spaces provides access to digital fabrication technology in the form of an open-door modus operandi workshop where individuals and entrepreneurs have the ability to get accustomed with 3D printers and other, various, fabrication equipment for their own purposes ranging from recreational equipment to technical objects and prototypes with a future mass production potential. Makerspaces offer access to the tools and techniques of digital fabrication to the average user. This is of paramount importance for potential individual makers, start-ups and small and medium-sized enterprises (SMEs). Not only will this target group receive the actual 3D printed part at the end of the process, but it will also acquire deep knowledge about its design development, fabrication and financial cost aspects. The existence of makerspaces itself, contributed immensely in the initial development and commercial expansion of desktop, low-cost 3D printing. The first such case was the RepRap concept (abbreviation of the words "self-replicating rapid prototype"). It wasn't until 2005, where Dr Adrian Bowyer founded the aforementioned project which had to do with the fabrication of an open source 3D printer whose parts could be easily obtained by local suppliers. The printer used ABS and PLA Thermoplastic Polymers in the form of filament reels and featured an extruder that melted and subsequently deposited the melted material in a layer upon layer principle. The vision of its creators was the 3D printer's ability to replicate itself, thus being a suitable fit for a Fab Lab's inventory. Indeed, many Fab Labs adopted the RepRap project and not only utilized it for their needs but performed alterations and improvements in it ([37] Pearce *et al.,* 2010). This effort that started and was carried out inside the Fab Lab network, led to the creation of two other 3D printing projects, the "MakerBot" and the "Ultimaker". The Makerbot project started in 2009 with the aim of creating 3D printers that would be affordable and fully functional [[56],[41]]. During this year their first 3D printers became commercially available, attracting a community of roughly 2500 users by 2010. Eventually, in 2013 the company was acquired by Stratasys Inc. for over $400 million. The Ultimaker project arose in 2010 from the Dutch Fab Lab of Utrecht, in an attempt to offer a 3D printer that would be more functional and efficient compared to the original RepRap. Ultimaker offered their first commercial 3D printers in the form of DIY self-assembling kits in 2011, where the buyer had to assemble the kit. ([41] Pettis *et.al.* 2011).In this context, it is easily understood that 3D printers are a vital part of every makerspace. Studying the Fab Lab creation timeline, it is evident that 3D printers were not included in their initial inventory mix. However, starting with the "RepRap" project, 3D printers became a core part of Fab Labs and offered an unprecedented manufacturing ability that was offered in an accessible and open source way. This gave the opportunity for Fab Lab participants not only to use them for their projects but also to get accustomed to them in a way that led to the improvement of desktop 3D printers and the launch of several successful commercial projects. Fig. 3, depicts a makerspace facility.

3.2. Reasons for choosing a Fab Lab or makerspace in order to have access to 3D printing technology

Makerspaces have made a great contribution towards making 3D printing accessible to a large number of users. The majority of makerspaces offer their participants access to a variety of affordable 3D printers ranging from desktop FDM printers to desktop SLA printer category. This is an interesting distinction/finding due to the fact that the majority of more traditional workshops are not that specialized in 3D printing and they do not offer it as much ([26] Hug, "State of Makerspaces Survey Results" [Online]). In this context, the equipment offering as well as the specialization towards this technology is evident on the makerspaces' behalf. The key question to be answered is why should an individual or a company choose a makerspace in order to have access to 3D Printing technology.According to available data, makerspaces are a rather affordable way to have access to this technology. Most of them (roughly 73%) operate with a not-for-profit operating scheme with their income being derived from government subsidies, organized workshops and events, contracts with corporations and membership fees. Therefore, member-

Fig. 3. A makerspace facility.

ship remains quite attractive being either completely free or ranging from 1 to 100$ for the vast majority of makerspaces ([26] Hug, "State of Makerspaces Survey Results" [Online]). This is also the case for organized workshop fees which are either completely free or ranging from 1 to 40$ ([26] Hug, "State of Makerspaces Survey Results" [Online]). Makerspaces offer a truly personalized 3D printing experience that has an educational allure. Participants have the benefit of being advised and supervised by trained, experienced staff on many aspects. This can be in the evaluation of the proposed design to be submitted for fabrication and, potentially, its modification towards better fulfilling the participant's needs. Then, the participant will learn how to prepare the design for 3D printing by utilizing the dedicated slicing software, learning how to tweak the process parameters. Soon afterwards, the participant will be physically present throughout the 3D printing process, observing and understanding how this technology operates. At the end of the process, the participant will also learn about post-processing procedures that will lead to the best possible surface finish quality. One might argue that this kind of information is already available on relevant websites and forums. However, makerspaces excel due to the presence of the trained advisory human capital that they can offer to the participants. Such staff is always present to offer guidelines, exhibit technical procedures and answer specific questions that each participant might have. In this way, makerspaces offer a full participatory experience that has both educational and somewhat recreational elements. In this context, makerspaces seem to be suitable spaces in order to have access to 3D printing technology for educational purposes. Constructivist learning theory, developed by Seymour Papert, expresses the belief that building artifacts and sharing with peers promotes the children learning process more than traditional learning ([8] Alía et al., (2019), [40] Peterson, (2012). This so called "Active learning" (AL) educational approach is based on competences focus, rather than plain knowledge and skills gaining ([42] Prince, 2013). In makerspaces, participants, embrace this approach and, by employing the relevant equipment, promote their initial ideas and critical thinking ([8] Alía et al., 2019). Thus, students learn by actively participating through this process gaining in-depth knowledge about innovative manufacturing engineering techniques like 3D printing ([18] Dreessen and Schepers, 2019, [21] Giannakos *et. al.,* 2017). In addition, other emerging technologies like Virtual Reality can be used for various applications towards this direction ([22] Gibson, 1993, [24] Gibson *et.al.,* 2002). 3D printing technology, in general, is considered as a technology that can make great contribution in this greater context ([52] Thompon *et.al.,* 2016, [23] Gibson, 2017, [15] Campbell *et.al.,* 2012).

4. The outsourcing trend

Business Process Outsourcing (BPO) has emerged as one of the top economic issues business of our time. The term Outsourcing (subcontracting) is used in various situations but, generally, requires the assignment of a task/activity (usually one that is made by the same activity holder) for an external partner to run. In this way, two parties (companies/organizations) are contractually bound for one party to perform one of the activities for the other party for a fee. The idea of outsourcing is certainly not new. Recruiting a group of qualified people to produce a particular work dates back to ancient times. Explorers, mercenaries, and merchants are just some examples of the concept of outsourcing. Even the term outsourcing is not that new. It was first used in 1970 by members of the construction industry and was gradually adopted by other sectors ([39] Persaud and Floyd, 2013).

4.1. Outsourcing and 3D printing

In the greater 3D printing context, we define outsourcing as the use of external service bureaus to 3D print parts on a contracted basis. These service bureaus, in most cases, have higher end industrial quality 3D printers that may be out of the scope of makerspaces. Many of these companies allow not only the direct uploading of part files and automated quotation systems, but also allow customers to use the service bureau's site as a virtual shopfront for their products. The advancement of internet networking has helped towards the direction of outsourcing where manufacturing companies are linked together in a network that connects every partner together ([17] Dong *et.al.,* 2008). Presently, many product components are being manufactured by outsourced contractors on a global scale. 3D printing technology can help towards boosting the design and manufacturing productivity in terms of speed productivity and economy. In this direction, industrial designers and home users can send their design to an outsourced 3D printing service bureau, which means that they do not need to own or invest in the high-end high-cost machines that the bureaus have. Therefore, the new tendency is to use the dedicated 3D printing service provider website in order to upload their unique design, chose 3D printing equipment used for the fabrication process and wait for the final item to be shipped back to them ([28] Kietzmann *et.al.,* 2015). In this context, a new marketplace of 3D print files arises ("[7] The disruptive nature of 3D Printing", [Online]).

Such outsourced services have seen a tremendous evolution in the last few years and have started to become a viable alternative to owning a personal desktop 3D printer. An outsourced 3D printing service can be defined as a third-party provider who is in a position to fabricate a 3D printed object and sell it to a client. Although there exist some service bureaus who print on desktop quality 3D printers, which offers limited advantage over the customer owning their own printer or using a makerspace, the vast majority of them have higher-end industrial quality 3D printers that would be unaffordable to the customer or makerspace to own ([9] Al-Azzawi et al., 2020). The client can be defined as a single individual or as an enterprise who wants to fabricate a 3D printed object and is willing to pay a fee to the 3D printing service bureau for this service. The client in most cases doesn't own a 3D printer or the 3D printer owned is not suitable for the attempted quality of 3D fabrication. In this way, decentralized local manufacturing of consumer goods will become more prevalent in coming years. Benefits such as cost and time savings, improved responsiveness and flexibility, management of demand uncertainty and inventory reduction can be achieved ([44] Rayna and Striukova, 2016). Outsourced 3D printing services is a fast-growing trend in the global market, and offer a good alternative to major companies that are looking into and investing in this emerging additive manufacturing sector. In 2013, eBay launched a new iOS application (eBay Exact) which enabled users to browse and purchase customizable 3D printed merchandise from MakerBot, Sculpteo, and Hot Pop Factory companies ([44] Rayna and Striukova, 2016).

Most outsourced 3D printing services operate online. The first such company was Ponoko which started its operation in 2007, followed by Shapeways, i.materialise, and Sculpteo, Protomold, Stratays Direct, and countless others. Thingiverse, Staples, 3DHubs, MakeXYZ, UPS and Amazon are just some of the larger companies that are active in this sector ([44] Rayna and Striukova, 2016). They operate websites where companies and interested users can sell 3D designs of their designed objects to customers. These designs can be fabricated and shipped directly to the buyers as depicted in Fig. 4.Fig. 5.Fig. 6.Fig. 7.Fig. 8.Fig. 9.Fig. 10.Fig. 11.Fig. 12.

Fig. 4. A 3D printed object fabricated and shipped directly to the client by an outsourced 3D printer service.

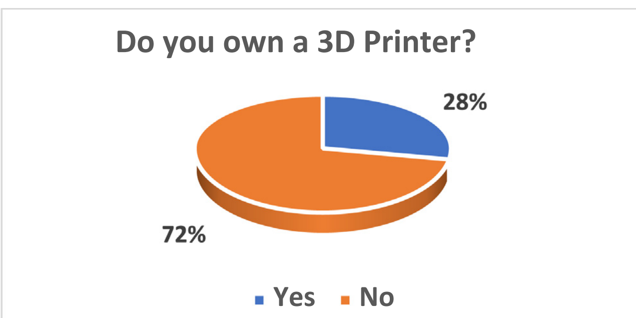

Fig. 5. Chart depicting the answers to the question Do you own a 3D printer?

4.2. Reasons for choosing an outsourced 3D printing service

A big question to be answered is what triggered the launch of such services. Many different reasons make users decide to use the 3D printing bureaus. The level of detail and accuracy offered by low-end desktop 3D printers is still considered insufficient for the production of quality products, like utilitarian goods or spare parts ([44] Rayna and Striukova, 2016). The desired material is also another demand seldomly met by low-end desktop 3D printers. In most cases, such printers use polymeric thermoplastic materials like PLA and ABS. If a user wants to print i.e. in metal, this requires elevated cost equipment which is very high for an individual user. From an industrial context, the introduction of this technology for rapid prototyping did not immediately see businesses change their business models and go purchase in-house industrial level 3D printers. The most important reason for that was the fact that such equipment pricing for purchase, use and maintenance, was very pricey. They therefore relied on external service bureaus to produce their prototype parts for them. Especially aircraft and automotive enterprises, who were the main users for rapid prototyping operations, blamed elevated relevant costs that prevented them from massively adopting this technology 2 decades ago ([54] Torres and Gati, 2011). A recent survey performed by StratasysTM, which is one of the biggest 3D printer manufacturers, highlighted the four most important reasons to use a 3D printing service. The answers ranged from: access to advanced equipment and materials (73%), less investment risk (60%), produce parts not able to be manufactured internally (53%), and access to AM expertise (47%) ([51] Stratasys Direct, Inc., "Trend Forecast 3D printing's imminent impact on manufacturing", [Online]). Access to advanced equipment and materials is a need, set by the fact that the customers' 3D printing applications have evolved. Better printing quality in most cases is achieved by investing in the purchase of a 3D printer with higher specifications. However, individual users and small and medium-sized businesses cannot always afford such an investment. Nowadays, clients are in need of a complete 3D printing package offer including vast material choices, end-processing and assembling services, offered by service bureaus due to lacking financial budget or technical expertise to perform such processes internally. Smaller investment risk is always welcomed, especially when having to invest in 3D printing equipment. Investments have to be made in training, software setup, purchasing consumables, and constant maintenance operations. The case described makes companies more hesitant, and the ability to use a 3D printing service bureau as an initial tryout can be a decisive first meditative step. On the other hand, the ability to fabricate objects that couldn't be fabricated in-house can be a real force multiplier for all kinds of enterprises. 3D printing service bureaus arise as the right complement to in-house printing operations. Companies already owning 3D printing equipment can

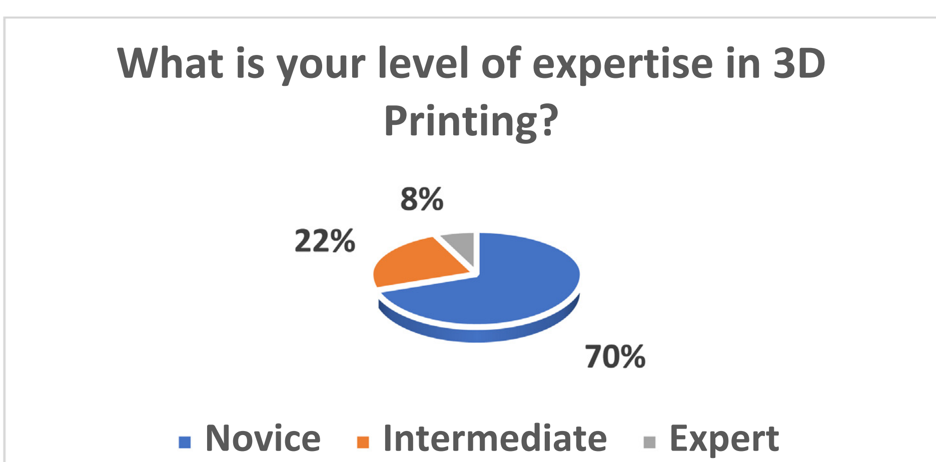

Fig. 6. Chart depicting the answers to the question What is your level of expertise in 3D Printing?

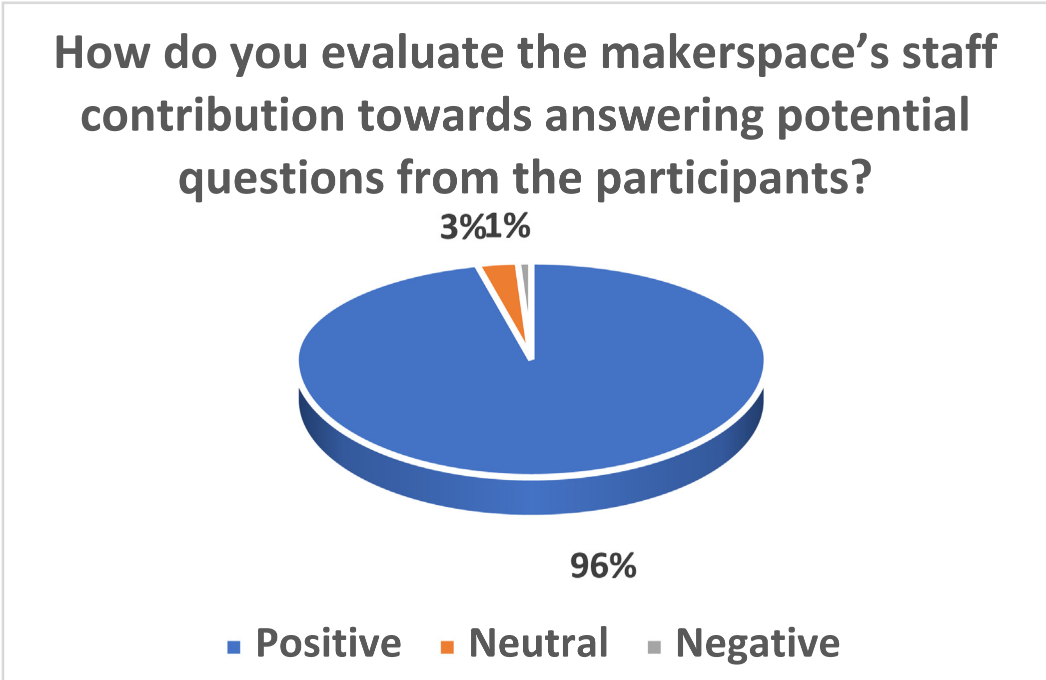

Fig. 7. Chart depicting the answers to the question How do you evaluate the makerspaces staff contribution towards answering potential questions from the participants?

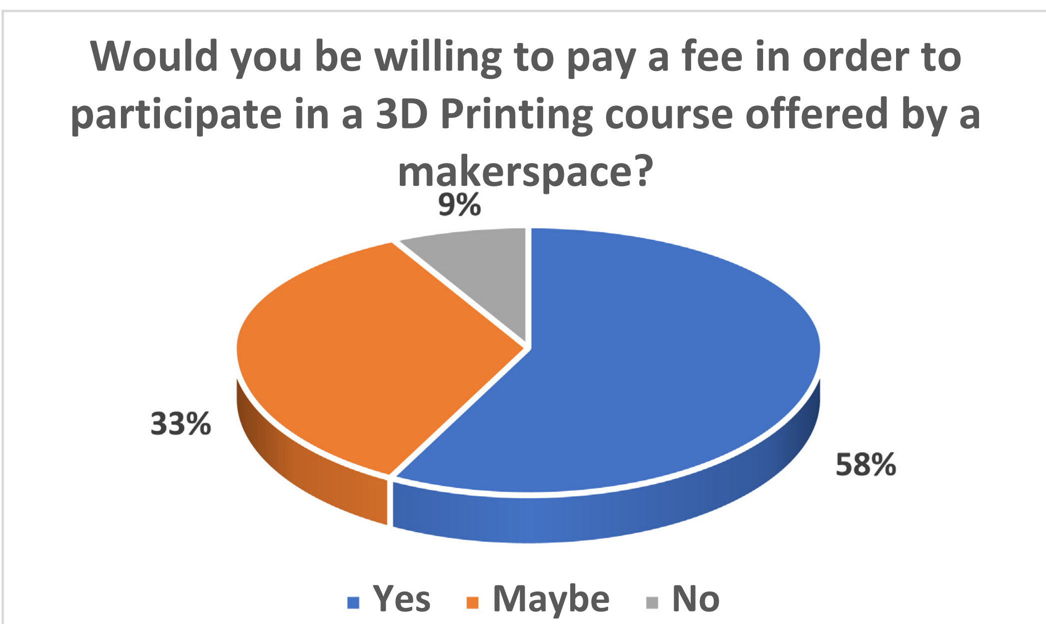

Fig. 8. Chart depicting the answers to the question Would you be willing to pay a fee in order to participate in a 3D Printing course offered by a makerspace?

choose a service bureau to experiment with new materials or processes not internally available. This is also the case for conventional manufacturing equipment owners who now have the option of customized fabrication in order to boost productivity on the manufacturing floor. In addition, access to already established expertise is also considered as a decisive factor for choosing outsourced 3D printing services ([58] Zhang et al, 2021).

5. Research methodology

In an attempt to further clarify the factors that motivate users to choose to participate in makerspaces or use the services offered by an outsourced 3D printing provider, a survey was conducted to participants in the University of West Attica makerspace as well as the "Bluelab" makerspace. Both makerspaces offer free access to their equipment while, also, offering free 3D printing and 3D design seminars to their users ([12] Barik et al. 2021). The survey was conducted from June 2020 to September 2020 and the participants filled in a questionnaire comprised of eight questions in

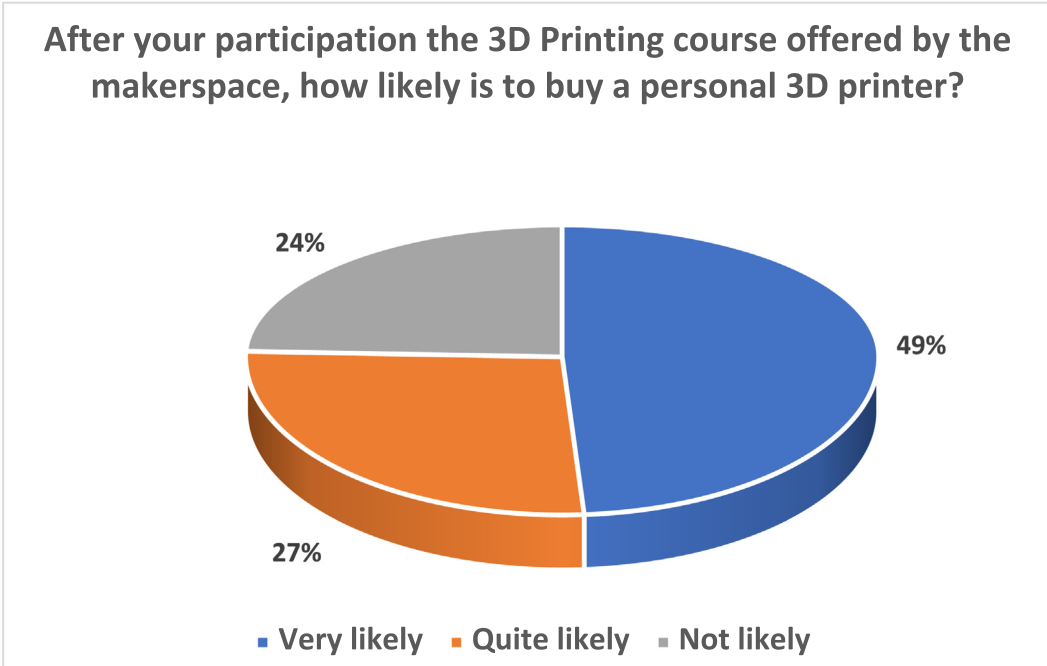

Fig. 9. Chart depicting the answers to the question After your participation the 3D Printing course offered by the makerspace, how likely is to buy a personal 3d printer?

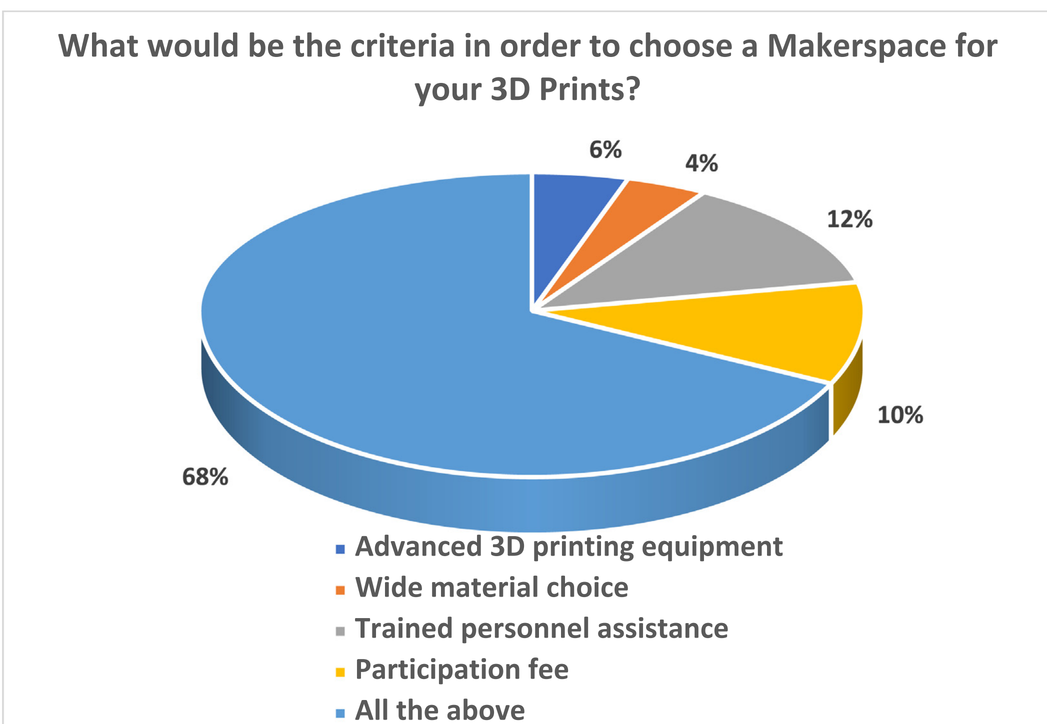

Fig. 10. Chart depicting the answers to the question What would be the criteria in order to choose a Makerspace for your 3D Prints?

total. The number of participants that took part in the survey was ninety (90) people with ages ranging from 25 to 57 years old. Their educational level ranged from high school graduates to holders of master degrees. The first questions were compiled in a way that would assess the users' degree of involvement with the 3D printing technology, i.e. whether they own a 3D printer or not and what their level of expertise was with the aforementioned technology. Then, the next question had to do with the participants evaluating the makerspace's staff contribution towards answering potential questions in an attempt to investigate the potential value of having highly qualified staff to directly address potential questions arising from the participants during the manufacturing/educative process. Another important aspect that the authors wanted to investigate, was whether the participants would you be willing to pay a fee in order to participate in a 3D Printing course offered by a makerspace. That was considered important, since the survey's partic-

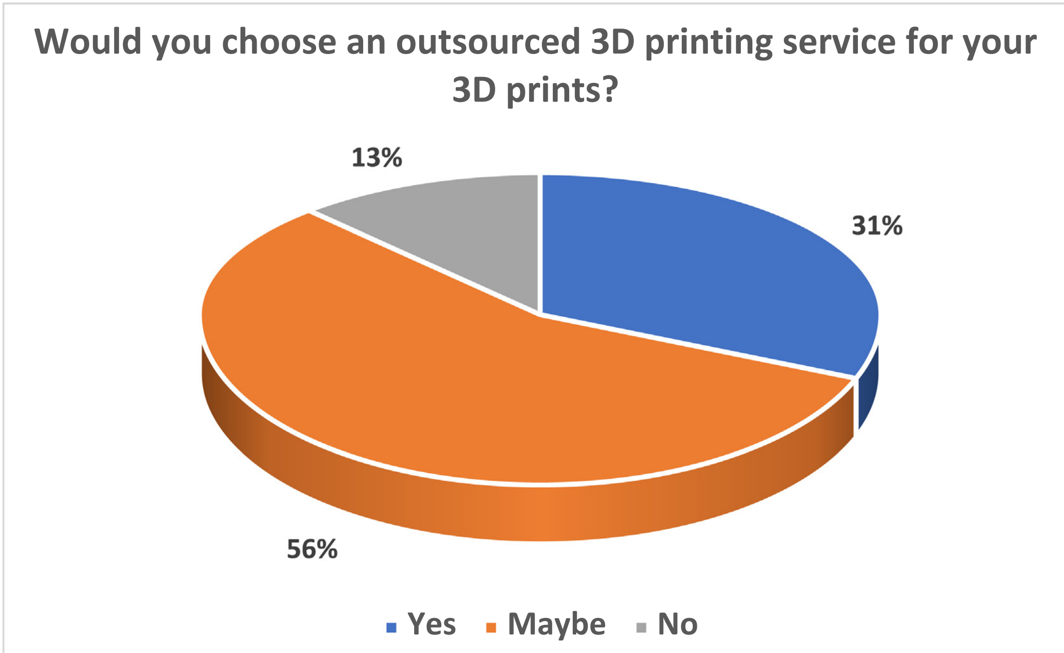

Fig. 11. Chart depicting the answers to the question Would you choose an outsourced 3D Printing service for your 3D prints?

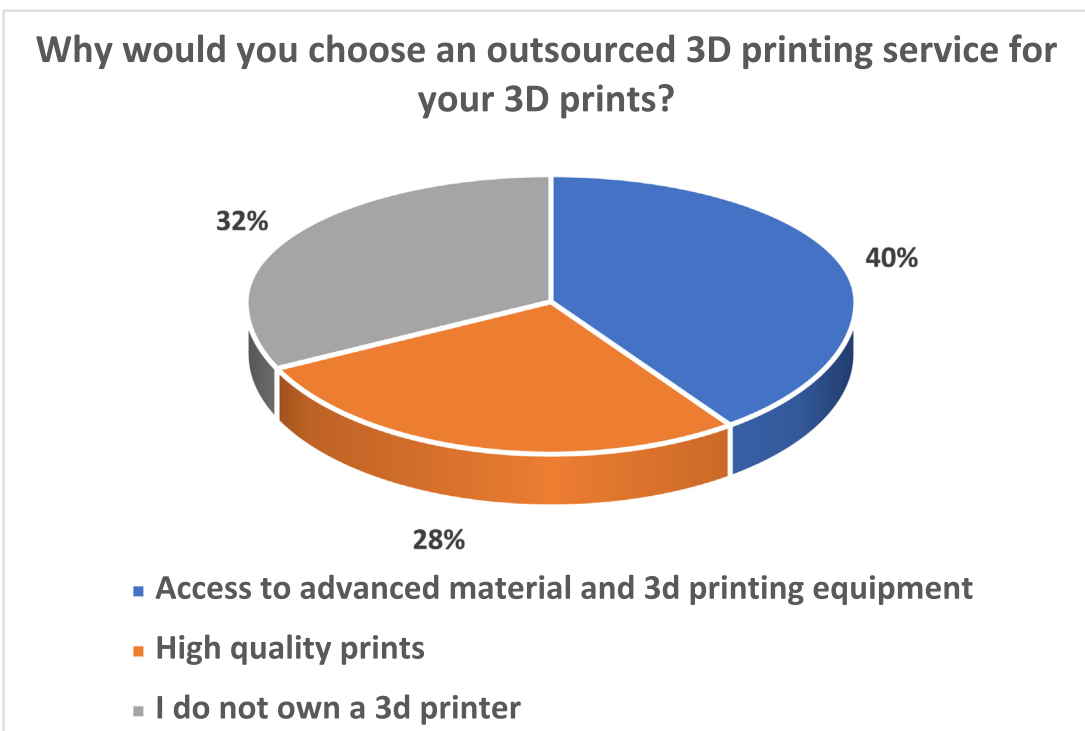

Fig. 12. Chart depicting the answers to the question Why would you choose an outsourced 3D printing service for your 3D prints?

ipants accessed both makerspaces free of charge, and it was desired to know whether this was a decisive factor for them. Then, after the completion of the offered educational seminars, the next question to be answered was how likely it was for a participant to buy a personal 3d printer. This question was given in order to determine whether a participant felt that it was worth buying a personal 3D printer after the completion of the 3D printing seminar ([13] Barik et al. 2021 A). In the same spirit, the participants were asked about what would be the criteria in order to choose a makerspace for their 3D Prints. In this question, participants were given a choice of answers that authors believe best summarize the most important criteria for a user to choose a makerspace. Finally, the survey ended with two questions regarding outsourced 3D printing service providers, highlighting this arising trend that features some unique advantages ([55] Thivagar et al.2020).

6. Results

Data from the survey conducted in the two aforementioned makerspaces are presented in this section. The participants' answers to the questions stated in the previous section are shown in the following charts: The answers to the question "Do you own a 3D printer?" show that 72% of the participants did not own a 3D printer while 28% did. This percentage variation indicates that the majority of the participants wanted to learn about 3D printing and broaden their horizons on this technology. On the other hand, 28% of the participants stated that they owned a 3D printer showing that users already owning such equipment wanted to learn how to improve their prior experience with this technology and possibly to tackle any potential problems that they faced with it. The answers to the question "What is your level of expertise in 3D Printing?" show that the 70% of the participants had little to no experience with this technology. On the other hand, 22% stated that their level of expertise was intermediate, while 8% stated that their level of expertise was expert. The sum of participants with intermediate to expert level of expertise reaches 30% which shows that even people with experience with this technology believe that they can benefit from a 3D printing seminar/course in order to improve their abilities. The answers to the question "How do you evaluate the makerspace's staff contribution towards answering potential questions from the participants?" show that the 96% of the participants believe that potential questions were successfully addressed by the makerspace's staff, emphasizing the more personalized experience that the users have when they deal with a physical space were qualified personnel is there to help. The answers to the question "Would you be willing to pay a fee in order to participate in a 3D Printing course offered by a makerspace?" show that the 58% of the participants feel that they would be willing to pay a fee in order to participate in a 3D Printing course offered by a makerspace, while 33% feel that maybe they would. On the other hand, 9% of the participants are negative towards paying a fee. This small percentage (which if summed with the 33% percentage of participants who may or may not be willing to pay a fee) indicates that a participation fee is a factor worth mentioning for the operation of a makerspace facility. The answers to the question "After your participation the 3D Printing course offered by the makerspace, how likely is to buy a personal 3D printer?" show that the 49% of the participants will very likely buy a 3D printer, 27% quite likely while 24% probably will not complete such a purchase. By personally asking this 24% of the participants in an attempt to obtain further information about their decision, their almost unanimous answer was that they will not buy a personal 3D printer because the makerspace offers them a variety of such equipment with zero to minimum costs, with a broad material choice as well as trained staff guidance. The answers to the question "What would be the criteria in order to choose a Makerspace for your 3D Prints?" show that the 6% of the participants believe that advanced 3D printing equipment is an important criterion, followed by 4% for wide material choice, 12% for the makerspace's trained personnel assistance, 10% for the participation fee and 68% for all the aforementioned criteria. This shows that the participants' decision to visit a makerspace falls under an umbrella of criteria were every single one of them has its unique importance but the final decision is dictated by all of them. The answers to the question "Would you choose an outsourced 3D Printing service for your 3d prints?" show that the 31% of the participants would indeed choose such a service, while 56% were in the "Maybe" category. These two percentages added, show that outsourced 3D printing services truly offer an alternative to owning a 3D printer and is a well-known potential choice among the participants. On the other hand, a small percentage of 13% would not choose an outsourced 3D printing service provider and would prefer to complete their 3D prints on their own or within a makerspace.The answers to the question "Why would you choose an outsourced 3D printing service for your 3d prints?" show that the 40% of the participants would choose such a service because of the offered access to advanced material and 3d printing equipment, another 28% percent because of the guaranteed high quality prints and 32% because they did not own a 3D Printer.

7. Conclusion and future work

The article investigates the impact of makerspaces and outsourced 3D printing bureaus to the additive manufacturing field and to highlight how individual users and companies can benefit in order to gain access to 3D printing technology in the best way possible. 3D printing techniques were initially introduced in order to overcome limitations in prototype fabrication. However, the maturation of this technology has made it relevant to a continuously growing target group. Especially in the last few years, the introduction of a reasonably priced desktop 3D printers has made them really easy for anyone to purchase. Makerspaces offer a personalized 3D printing experience for their users. Through a participatory process user physically attend all the stages of the process (design evaluation, 3D model preparation in a slicing software, fabrication stage and post-processing procedure) and gain all relevant knowledge in an active learning (AL) environment. This process has an extra added value of being carried out by experienced tutoring staff that is available to answer all possible questions regarding the process. In this context, they appear to be the optimal places for educational purposes especially when STEAM educational practices need to be performed. Due to their non-profit or low subscription operating scheme, they are also an inexpensive way to access 3D printing technology. However, this funding scheme (especially when there is public funding involved) along with the need of physical presence in such spaces usually makes them preferable for students, hobbyists, start-uppers and individuals in general rather than established large companies.On the other hand, outsourced 3D printing service bureaus offer an online service that does not require the physical presence of the client. They offer a 3D printing package starting from printing the customer's design through a wide range of materials, finishing and assembly services as well as shipment back to the customer's door, for a certain price. Many reasons attract users to use those services. The most important ones are access to higher-end technologies (SLS, metal, industrial FDM and SLA, etc.) and their raw materials, lower investment risk, ability to fabricate parts that cannot be internally fabricated and access to greater relevant technical expertise. Such service bureaus owe their existence to the general outsourcing trend that has emerged in the last decades and has utterly changed the way that companies do business. Outsourcing is an important modern reality in the business world. Outsourcing services continue to increase internationally, depicting the advantages that this practice offers. Makerspaces and outsourced 3D printing service bureaus are overlapping in their general 3D printer access offering but also have many differences. The most striking one is the participatory nature that makerspaces and Fab Labs provide. If this is desirable, then such spaces are probably the best choice especially for individuals that wish to learn how to operate a 3D printer. On the other hand, if this is not desirable and the time factor is pushing for fast access to a prototype or a custom part then outsourced 3D printing service bureaus may be the best choice. Another main difference is the usage fees. Makerspaces are, in most cases, much less expensive than outsourced 3D printing service bureaus. However, this is compensated by the guaranteed quality and the broader 3D printer inventory mix that an outsourced 3D printing services bureau offers. On the other hand, makerspaces make the perfect proving ground for users/inventors to develop and test their ideas at low cost, while assisted by the dedicated technical staff, before proceeding to their final 'production' prototype through an outsourced service bureau. There is, therefore, a natural progression from makerspaces to service bureaus. In this way, makerspaces and outsourced 3D printing service bureaus form a good comprehensive ecosystem for innovators and inventors to get their ideas form an idea to a ready for market product. These claims were backed up by a survey conducted in two makerspaces that the authors had access to. Participants of the survey indeed confirmed their interest in this emerging technology and find that makerspaces are physical spaces, with qualified staff that can help broaden their knowledge about 3D printing. At the same time, the majority of the survey's participants consider that outsourced 3D printing service providers are a very good choice for their prints due to factors like advanced material as well as 3d printing equipment and high-quality prints. In addition, such services are recognized as an established alternative for participants that do not own a 3D printer. n conclusion, makerspaces and outsourced 3D printing service bureaus have had a big impact in the additive manufacturing field by transforming this technology into a more widely accessible one. They can be seen as a big opportunity to transform 3D printing from a costly and unreachable technology to a fabrication technique available to everyone. One of the biggest gains is that the would-be entrepreneurs of tomorrow now have an affordable tool to test their ideas when conventional manufacturing methods were, in most cases, unaffordable (i.e. purchasing molds for casting) or even unsuitable for start-uppers and SMEs, traditionally causing hesitation and procrastination in launching new product lines from bigger companies.

CRediT authorship contribution statement

Antreas Kantaros: Writing – original draft. **:** . **Olaf Diegel:** Writing – review & editing. **Dimitrios Piromalis:** Validation. **Georgios Tsaramirsis:** Writing – review & editing. **Alaa Omar Khadidos:** Conceptualization. **Adil Omar Khadidos:** Methodology. **Fazal Qudus Khan:** Visualization. **Sadeeq Jan:** Investigation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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