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The Effects of the Use of 3D Printing Technology on the Entrepreneurs' Operational Effectiveness

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ABSTRACT

This paper examines the effects of the use of 3D Printing Technology (3DPT) applications on entrepreneurs' operational effectiveness. For this purpose, a study model based on the relevant previous studies was proposed. The data for this research was collected using a self-administered questionnaire given to 161 respondents. The target respondents were those employed in entrepreneurial companies in Jordan and the data was analyzed using simple and multiple regression techniques.

The findings indicate that the extent of 3DPT being used by entrepreneurial companies in Jordan was considered to be moderate at this stage and it varied among them in terms of their size and business experience. Further, all integrated effectiveness indicators (time, cost, quality, competitiveness and management processes) were significantly influenced by the level of the use of 3DPT; the most important effectiveness indicators were found to be time, cost and quality due to the business environment context found in Jordan.

Keywords: 3DPT applications, Effectiveness indicators, Entrepreneurial companies, Jordan.

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آثار استخدام تقنية الطباعة ثلاثية الأبعاد في الفعالية التشغيلية للمشاريع الريادية

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ملخص

تهدف هذه الدراسة إلى البحث في آثار استخدام تطبيقات تقنية الطباعة ثلاثية الأبعاد في الفعالية التشغيلية للمشاريع الريادية. ولتحقيق هذا الهدف، فقد تم بناء أنموذج للدراسة يعتمد على الدراسات السابقة ذات الصلة. وقد تم جمع البيانات الخاصة بهذا البحث باستخدام استبانة معدّة ذاتياً، من 161 ريادياً. وكان المستهدفون هم الذين يعملون في شركات الأعمال الريادية في الأردن، وتم تحليل البيانات باستخدام تقنيات تحليل الانحدار البسيط والمتعدد.

تشير النتائج إلى أن مدى استخدام DPT 3 من قبل شركات الأعمال الريادية في الأردن يمكن اعتباره معتدلاً في هذه المرحلة، ووجد أن هناك تبايناً بين هذه الشركات في مدى الاستخدام يعود إلى الحجم والخبرة التجارية للمشاريع التي يعمل فيها الرياديون. علاوة على ذلك، وُجد أن جميع مؤشرات الفعالية (الوقت والتكلفة والجودة والقدرة التنافسية والعمليات الإدارية) تأثرت بدرجة ذات دلالة إحصائية كبيرة بمستوى استخدام DPT 3. وقد وجد أن أهم مؤشرات الفعالية التي تحسنت باستخدام هذه التكنولوجيا هي مؤشرات الوقت والتكلفة والجودة. وقد يعزى ذلك لطبيعة بيئة الأعمال في الأردن.

الكلمات الدالة: تطبيقات الطباعة ثلاثية الأبعاد، مؤشرات الفعالية، الشركات الريادية، الأردن.

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1. INTRODUCTION

IT innovations fundamentally change business models; this is especially true of intelligent technologies, which have begun to make major changes in the industries that have used them. Gradually over the past two decades, new digital technologies have emerged that have turned many tangible products into intangible digital content.

This has also affected the manufacturing process, as designing and producing concrete products require companies involved in a long series of operations, all of which must be done in appropriate ways. These require different skills, professional staff and development time from idea to complete production, in addition to continuous development and adjustments during production, as well as any special requirements that depend on the product itself. All this costs a lot of money.

Recently, the trend of technology adoption has accelerated greatly due to the development of additive manufacturing (AM) technologies. 3D printing technology is often used as a synonym for AM and this is defined more precisely as "the process of linking materials to make objects from 3D model data, usually layer on layer, unlike subtractive manufacturing (SM) methodologies" (Wohlers Associates, 2010). More generally, AM is defined as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing technologies” (Niaki and Nonino, 2017). This technology can be used to print very complex designs, which is especially useful in the prototype stage of new product development, because it allows to increase the design value proposition by using this technology to get fast comments, make everything at home and reduce the cost of development operations, allowing the company to provide the maximum benefit of the product to the customer (Paros et al., 2017). However, 3D printing is an innovative sector in which technologies change rapidly. As companies face economic world changes and new consumption standards, the concept of AM manufacturing to produce physical objects from digital information layer-by-layer has become increasingly popular (Thompson, 2016; Al-Dmour et al., 2020). Additive manufacturing represents a local innovation in manufacturing technologies and thus may significantly change value chains and business logics in manufacturing industries (Steenhuis and Pretorius, 2017).

Additive manufacturing technologies have now advanced through three stages of development. Initially, product designers only used these products to develop new products (NPD). The second development phase of AM included its application in creating parts for end use, a move defined as "direct digital manufacturing". The third phase involves 3D printers that, as with desktop printers, can be used directly by end consumers (Berman, 2012). This phase has given entrepreneurial companies and industrial design studios access to AM processes, such as stereo lithography (SLA) and fused deposition manufacturing (FDM), with costs from $300 to $2,000. The purposes for purchasing these printers differ, ranging from fully producing products, such as accessories and toys, to producing complementary materials, such as covers, boxes or parts to help entrepreneurial companies develop their competitiveness. To further help such companies develop their competitiveness, changes must also occur in terms of cost, time and quality in both product and management process terms. Three-dimensional printing has thus become an essential element in a new industrial revolution in which digitization, information and communication are transforming product innovation. However, despite the many alleged benefits of 3DP, current research indicates that the expected benefits have rarely been examined in practice.

Understanding the factors influencing the use of 3D-printing applications has received considerable attention from academic researchers and professionals all over the world (Guo and Leu, 2013; Rylands et al., 2016; Martinsuo and Luomaranta, 2018). Other studies have emphasised the various benefits of adopting AM technologies, which include design freedom, efficiency and speed, customization of products, enabling of small batches, flexibility, adaptability, simplification of supply chains and reduction of waste (Weller et al., 2015). A review of previous studies also shows that the majority of the studies concerning challenges to AM adoption were carried out only among large firms (Flores et al., 2016; Rylands et al., 2017; Al-Dmour et al., 2020).

Studies empirically examining the use of this phenomenon among entrepreneurial companies in developing countries, such as Jordan, are rare; however, they focused particularly on the impact of the use of 3D-printing applications on operational effectiveness (time, cost, quality, competitiveness and management processes). Digital manufacturing technologies are regarded as offering tremendous advantages for businesses and industries, but these benefits appear to be barely examined in practice. Therefore, this study seeks to answer the following question: To what extent does the use of 3D-printing technology improve the operational effectiveness of entrepreneurial companies in a Jordanian business context?

2. Theoretical Background and Literature Review

2.1 Three-dimensional Printing Technology: Definition, Benefits and Limitations

Three-dimensional printing technology (3DPT) is still a hot topic in the innovation world; this is one of the reasons behind this study. Due to its newness, however, there is no clear definition for this technology, which might also be since the additive manufacturing industry faces a lack of categories for grouping AM technologies, which can be educationally limiting, especially when communicating information in both technical and non-technical settings. There are many definitions of AM in various contexts; thus, this work adopts the most recent and meaningful definitions generated by technical experts and academics. Most of these clarify the processes behind the production and creation of parts and objects using a 3D printer. While some IT experts prefer to limit the term 3DP to those units and devices with inkjet-based print nozzles that can create objects using a layer-by-layer method, others apply the term to the office or consumer versions of Rapid Prototyping (RP) devices that are comparatively low-cost and easy to use (Casey, 2009).

Companies must thus work hard to determine the value that 3D printing may have for them; although opportunities for product improvement are apparent, how to generate value from them may not be as clear. Companies must first examine the potential and risk of these techniques across three dimensions: product innovation, customization and complexity, setting clear boundaries for the customization required and permitted, to locate the 3D printing mode within their organizations. The American Society for Testing and Materials (ASTM) defines AM as a process of joining materials to make objects from 3D model data, usually in a layer-upon-layer format as opposed to subtractive manufacturing methodologies (ASTM, 2013). It defines 3D printing more accurately as “the fabrication of objects through the deposition of a material using a print head, nozzle or another printer technology” (ASTM, 2013). While the term 3D printing is often used synonymously with additive manufacturing, it is also associated with machines that are low-end in price or overall capability. In this context, the ASTM defined Rapid Prototyping (RP) as "additive manufacturing of a design, often iterative, for form, fit or functional testing or a combination thereof" (ASTM, 2013). AM technology may also be referred to as additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing and free-form fabrication. To maintain standards, the ASTM has decided to allow the revision of its definitions at any time by the responsible technical committee; these must also be reviewed every five years and revised, reapproved or withdrawn.

AM technology has been successfully adopted by many industries, including automotive, aerospace, (Jong & Bruijn, 2013), electronic, medicine, art, fashion, robotics, jewellery and architecture industries. The primary applications of additive fabrication have been in design and modeling, fit and function prototyping and direct part production. The use of 3D printing is now increasing in many markets (Birtchnell & Urry, 2013). Berman (2012) indicated that 3D printing technologies are now used more to create customized products, prototypes and replacement parts, as well as in medical/dental applications and bridge manufacturing. Usage is increasing in many fields of this type (Alpern, 2010). In the early 1990s, the formation of rapid tooling was promoted by the use of heat-resistant polymers and metal alloys in 3D printers, although this was in the early stages of 3D printing. Their initial success may be partial, because traditional moulds before the advent of 3D printing were built of aluminium and steel and took quite a long time to create, while moulds produced by 3D printing technology take only a few hours to generate (Hiemenz et al., 2013).

Gibson et al. (2010) noted that 3D printers have now become much more accurate in terms of quality, accuracy and material properties. The term 3DP refers to a range of additive manufacturing processes that create products by building up layers of plastic, metal or other materials directly from digital design files (Holmström and Partanen, 2014; Petrovic et al., 2011). This definition covers a wide range of processes and technologies that use light or heat to create physical objects from polymers, powders or filaments, without the penalties traditionally imposed on costs by the need for specialized tools at low production volumes (Weller et al., 2015).

According to Holmström, Partanen, Tuomi and Walter (2010), the reasons underlying the success of 3D printing technologies include the fact that 3D printing offers a full set of advantages as compared to subtractive processes and thus provides an attractive alternative for product manufacturers. According to Wohlers Report (2016), adoption rates of 3D printing continue to grow and the equivalent 2018 report puts the number of estimated desktop systems sold at around double the number given in the 2015 data published in the 2016 report. Hundreds of thousands of 3D desktop printers have been sold across the world between 2015 and 2017. Khoo et al. (2015) indicated that 3D printing includes any process that builds a 3D object layer-by-layer from a 3D model, whether with resin or other materials. They added that 3D printing is used to fabricate prototypes, mock-ups, replacement parts, dental crowns, artificial limbs and even bridges. Asadi-Eydivand (2016) stated that 3D printing is deemed to be a suitable tool to produce complex internal and external porous structures, while Wu and Chen (2018) mentioned that 3D printing is a cheap and very efficient tool, especially in the forms of selective laser sintering (SLS) and stereolithography. Chen (2017) argued that 3D printing had been incorporated into at least one convenience store chain in order to create a ubiquitous manufacturing network, adding that 3D printing is considered to be a unique manufacturing process from the manufacturing perspective.

According to several academic studies, AM technology has several advantages over traditional manufacturing, including cost, speed, quality, innovation and transformation. Attaran (2017) indicated that the advantages of 3D-printing in terms of manufacturing have become more prolific as technology has continued to advance in flexibility and capability. There has also been an exponential growth in the number of materials a 3D-printer can use to build objects (Schniederjans, 2017). Other researchers have claimed that small companies are more likely to adopt 3DPT than large companies (Lopes da Silva, 2013; Mellor, Hao & Zhang, 2014). The core of any business is to grow and to sustain such growth and because this technology increases innovative capacity, it creates additional opportunities and expandability, allowing firms to add extra market share (Weller et al., 2015).

Furthermore, AM technology allows the flexible production of custom products without increasing manufacturing costs significantly due to the use of direct digital manufacturing processes that convert 3D data directly into physical parts without the need for specialized tools or templates. The category manufacturing principle can also produce functionally integrated parts in a single production step, reducing the need for assembly activities. Thus, AM technology significantly affects flexibility, customization, capital costs and marginal production costs (Berman, 2012; Ford and Despeisse, 2016; Weller et al., 2015).

However, AM opportunities are not unlimited: the materials available do not always match the characteristics of traditional manufacturing processes, productivity is reasonably low and most manufactures still require additional surface finishes to be added; also, specific quality control standards have not yet been established (Berman, 2012; Gibson et al., 2010). While these constraints may be temporary, diminishing with technological development, there is also a more significant threat inherent in AM in conjunction with 3D scanning and reverse engineering capabilities. AM poses severe risks to intellectual property rights in terms of product designs (Berman, 2012). AM generally refers to digital production, moving from full digital representation to output. Copying a physical product and turning it into 3D data is becoming relatively easy and may disrupt the market; in the same way, copying a printed document and sharing ordinary computer files have caused disruptions in the publishing and music industries (Wilbanks, 2012).

2.2 Three-dimensional Printing Technology (3DPT) and Operational Effectiveness

Technology has been reported as being one of the most crucial factors for enhancing companies' competitive advantages, business growth and operational effectiveness. While entrepreneurial business has increased in importance throughout the world, such businesses must remain suitable for their purposes. Over the past decade, many entrepreneurs' businesses in developed countries, such as the USA, UK, Germany and other European countries, have recognized the advantages of the adoption of digital technologies, being mainly motivated by the low-cost advantages. Recently, the relationship between the adoption of digital technologies and entrepreneurs' operational effectiveness has also received more considerable attention in the organizational and entrepreneurial literature, with several researchers indicating that digital technologies, such as 3DP, can contribute to business effectiveness in at least two important ways (Mishra et al., 2013; Lu and Ramamurthy, 2011). The first is that digitally conducting business operations increases efficiency and offers assistance in overcoming uncertainty. The second is that improved IT helps coordinate and synchronize business functions, such as innovation, product design, manufacturing and marketing (Bharadwaj et al., 2007; Candi and Beltagui, 2019). Adopting digital tools in innovation can help entrepreneurs' companies achieve successful results from innovation projects (Marion et al., 2015) and the relationship between flexible manufacturing systems, such as 3DP and product innovation, is a logical one, which has also been empirically tested (Oke, 2013). As a result, the use of 3DP is expected to be associated with higher business effectiveness. Steenhuis (2017) further claimed that the adoption of 3DP technology could affect businesses by improving their operational efficiencies: quality, speed, flexibility and reliability.

According to Oettmeier and Hofmann (2016), operational efficiency is not considered as being radical as the strategic positioning effect of 3DP technology on business. The effects of 3DP technology can have a significant impact on the positioning (corporate image) of all players involved in the supply chain, who are suppliers, manufacturers and customers. The use of 3DP technology can make supply chains narrower, as it provides an opportunity for integration and optimization of product functions, to a certain extent reducing the need for sub-component suppliers. Thus, with the adoption of 3DP technology, processes become more flexible as technology changes product designs and provides high-quality services with decentralized production closer to consumer locations. Also, 3DP technology not only affects the supply chain structure, but also impacts the processes involved in the supply chain by offering new opportunities for product design through modified management and R & D processes. In this context, the adoption of 3DP technology facilitates changes in process planning and quality control processes.

In this study, the use of 3DPT is expected to improve the following operational effectiveness dimensions: time, cost, quality, competitiveness and management:

Time Effectiveness

According to Schniederjans (2017), the use of 3D printing technology allows rapid prototyping for companies, especially SMEs, allowing them to produce product models in a short time for quick testing and improving the delivery of on-time parts that fail in such testing. In this way, it not only improves the production process, but also enhances creativity in the development of products. Moreover, the use of 3D printing technology significantly reduces the costs of creating traditional models. Other potential benefits of the use of 3DPT include a reduction in time-to-market; material savings compared to subtractive manufacturing processes; a reduced need for tools, moulds or punches; enhanced density of final parts; and the fabrication of free-form enclosed structures (Schniederjans, 2017). Lead times can also be significantly lower with three-dimensional printing systems that can produce different forms of products simultaneously without additional switching costs or set-up time (Weller et al., 2015).

Cost-effectiveness

Examining cost in 3DPT usually includes three dimensions: printer cost, materials cost and operating cost. Kellens et al. (2010) indicated that 3DPT helps develop an optimal design, which leads to decreased material consumption of up to 40% (Achillas et al., 2015). All of these variables can be controlled and changed based on the quality and precision needed in the printed products; however, the type of 3DPT and the model of the printer also affect the costs. In some cases, the costs are also affected by the level of finishing required, such as sanding, colouring or any other post-processing required. Overall, 3DPT helps reduce labour costs as the 3D printing process is completely automated (Dedoussis & Giannatsis, 2009); this offers flexibility in the RP cycle for NPD and the lack of moulds and patterns also saves much money and reduces lead times (Rosen, 2014). This technology also lowers investment costs in terms of inventory space and its management (Müller and Karevska, 2016; Liu, 2014), as 3DPT works in near to Just-in-Time (JIT) manner, where there is no need for an extended factory space (Fawcett & Waller, 2014).

Entrepreneurs must determine the appropriate manufacturing techniques for their products in order to better adjust and control costs, especially in the early stages of product prototyping. Furthermore, there are advantages in many cases to decreasing the weight of the end product overall and increasing the strength-to-weight ratio (Horn & Harrysson, 2012), particularly in products used in aerospace and robotics applications (Yoon et al., 2014). However, 3DP technology cannot compete in terms of production costs at medium and large volumes in many cases (Ruffo & Hague, 2007), though additive manufacturing can reduce costs for products with intricate designs that are costly to manufacture using traditional methods. Furthermore, increasing use of additive manufacturing may lead to a reduction in raw material costs through economies of scale (Thomas, 2016; Ford & Despeisse, 2016; Baumers et al., 2017). Another significant advantage of adopting 3D printing technology can be gained from a supply chain perspective, as companies can manage product warranties, repairs and upgrades by offering customers downloadable 3D designs of the parts needed for such repairs.

Localized production is another benefit of AM, which allows the company to develop a business model that relies on contract manufacturing using its internal 3DP techniques. As 3D manufacturing carries relatively low costs, basically consisting of the cost of the machine and materials used, if a firm is producing economically small quantities of products, production can occur near to or even at the point of consumption (Mueller and Karevska, 2016). Thus, though 3DP affects many industries in different ways, the logistics sector is most at risk of disruption. Production shifted to locations closest to the point of consumption will significantly reduce transport costs and delivery delays within the supply chain. Recent research has shown that some logistics companies already apply 3D within their business operations and that companies that are not considering applying 3DP technology in their operations are hesitating mainly because of their lack of information about the potential advantages that this technology offers (Mueller and Karavska, 2016). This development means that production in developing countries will no longer be necessary, because companies can produce goods at the same low-cost point without bearing any transportation or logistics costs. Alongside these advantages, many new services are likely to appear as market barriers are lowered (Müller and Karevska, 2016).

Quality Effectiveness

One of the commonalities of most entrepreneurial start-ups is the desire and passion for creating new, creative and well-developed ideas that can be converted into right products that have a reasonable chance of acceptance in the market; these are favoured in the attempt to gain more loyal customers (Dimitrov et al., 2008). Thus, entrepreneurial start-ups invest much effort into their Research and Development (R&D) departments and spend much time in the NPD cycle in order to increase the quality of the fabrication to increase the value that customers can gain from the final product, offering entrepreneurial start-ups with significant competitive advantages (Gibson et al., 2010).

Many researchers have noted that 3DPT can notably improve overall product quality; however, it has many weak points such as poor surface quality, questionable accuracy of dimensions, a higher tolerance range of error and potential physical or mechanical issues (Miladinov, 2018; Petrovic et al., 2011). However, 3DPT does decrease costs and production time while increasing the general quality of results by merging various production operations (Atzeni & Salmi, 2012). Another example of positive application is the way 3DPT helps improve the quality of surgeries for broken bones (James, Slabbekoorn, Edgin and Hardin, 1998; Chaput et al., 2011). Such AM technology requires operators to receive proper training in order to know how to use it effectively, but 3DPT quality and reliability, especially in the FDM commonly used by entrepreneurs in start-up companies, still impede this technology and influence use speed in the consumer market. Miladinov (2018) claimed that one of the main advantages of 3DP is its sophisticated design capability, which increases efficient manufacturing and can thus bring products to the market in a shorter period. Undoubtedly, three-dimensional printing offers a more natural way to innovate by allowing the cheap design of prototypes that can be produced very quickly.

Concerning product design, 3DPT makes it possible to optimize any kind of product design according to product function rather than being restricted by manufacturing techniques or other obstacles in the supply chain. Customizing products to meet the needs of customers efficiently is also possible with three-dimensional printing and such customers are likely to be willing to pay more for the higher perceived value of these customized products. Three-dimensional printing not only allows companies to express their creativity in terms of product design, but also enables customers to participate in the design process, better satisfying their demands (Wheeler et al., 2015; Cerdas et al., 2015). Furthermore, as Kietzmann et al. (2015) pointed out, 3D printing technology offers environmental advantages, as 3D manufacturing reduces the environmental footprint of production by allowing the manufacturing process to happen closer to the point of consumption, thus minimizing distribution channels. Three-dimensional printing also dramatically reduces environmental pollution by not creating as much waste during the manufacturing process; failed objects produced by a 3D printer can even be reused as raw material for printing other objects.

Competitiveness Effectiveness

Many researchers have opined out that 3DPT is pushing the world towards another industrial revolution; indeed, it has stimulated manufacturers' imagination in terms of creating unique products or finding new manufacturing flows to achieve significant improvements for existing products, such as printing houses, vehicles or even human tissue. At base, 3DPT is an efficient mechanism that offers new types of competitiveness that help meet users' needs in a more direct way (Yang & Xue, 2003). It also offers excellent potential to increase competitive advantage within scales of production from small to medium, particularly about plastic components (Atzeni et al., 2010). The efficiency of objects produced from metal using 3DPT in small-to-medium scale productions has also been shown (Atzeni & Salmi, 2012).

According to Oettmeier and Hofmann (2016), companies not only aim to achieve technological progress, but also to develop competitive advantages that distinguish them from their competitors through highly innovative products and customized products that offer additional value to the customer. Based on this, three-dimensional printing is just the latest technological development adopted by companies to improve their technological capabilities. However, 3D printing has shown rapid technological development, offering more opportunities for companies to reach higher levels of manufacturing capabilities and thus enhance their competitive advantages (Rylands et al., 2016). It is thus clear why 3DP has been extensively adopted as one of the subversive innovations that generate radical industry changes.

While many of the benefits from 3DPT drive company and product competitiveness, many developing countries face the problem of losing competitiveness based on mass manufacturing as 3DPT develops (Petrovic et al., 2011). This has led such giants of mass production as China to adopt and invest resources into 3DPT themselves (Bai, Liu, Wang & Wen, 2017). The results of such adoption show growth in competitiveness of early entrepreneurial start-ups that have adopted 3DPT in RM, especially for companies with experience in AM (Khorram Niaki & Nonino, 2017). Adopting 3DPT can also provide a competitive advantage in uncertain markets that demand a great variety of products and adaptability to varying customer needs (Weller et al., 2015) as well as a shorter time to market (Khorram Niaki and Nonino, 2017).

Management Process Effectiveness

There are definite changes in management style and planning processes for those entrepreneurial companies that adopt 3DPT. Though these changes occur in various areas, such as infrastructure, material costs, waste materials, manufacturing space, inventory, manual or expert labour required and maintenance style, these require to facilitate logistics management to offer elasticity in the face of possible decreases in production costs (Petrovic et al., 2011). AM also affects supply chain management by minimizing the required stock holdings (Fawcett & Waller, 2014). Recently, the concept of “digital inventory” has become popular in supply chain management and the "digital inventory" management model allows production on demand for users, offering a JIT-like model of provision for firms that reduce storage expenses (Holmström et al., 2010), increasing inventory turnover (Tuck et al., 2006) and the ability to produce locally. AM also requires fewer tools during the production process and fewer labourers, changing the requirements for operating capital management (Berman, 2012).

3. Research Model and Hypotheses

The theoretical background and empirical studies regarding the effect of the use of 3DPT upon operational effectiveness of entrepreneurial companies (Schniederjans, 2017; Steenhuis and Pretorius, 2017; Martinsuo and Luomaranta, 2018; Rylands et al., 2017; Niaki and Nonino, 2017) were reviewed and integrated to develop a conceptual model to guide this study. The study model consists of the independent variable (the extent of the use of 3DPT) and the dependent variables (operational effectiveness indicators; time, cost, quality, competitiveness and management process). Reviewing the related studies and literature, a suggested model of the 3DPT influence on the operational effectiveness of entrepreneurial companies was built, as shown in Figure (1).

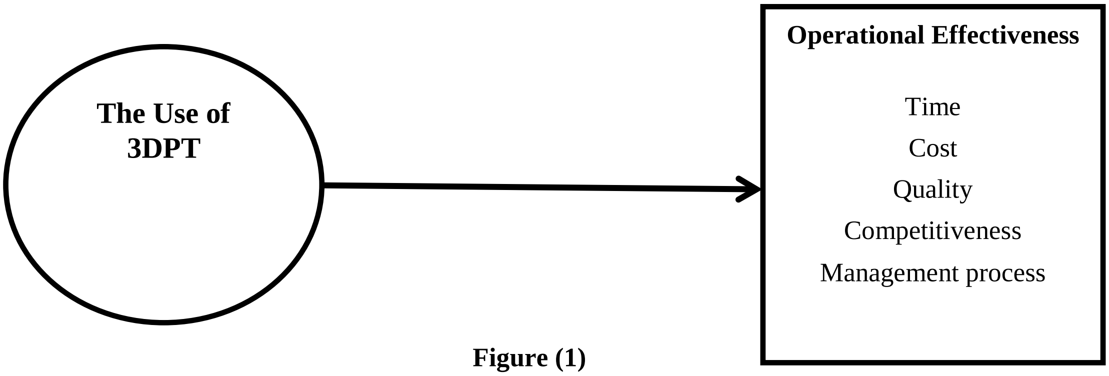

Figure (1)
Research model

The expected relationships between the independent and dependent variables were formulated into three hypotheses as follows:

Ho1: The level of the use of 3DPT is not significantly different among entrepreneurial companies due to their size.

Ho2: The level of the use of 3DPT is not significantly different among entrepreneurial companies due to their business experience.

Ho3: The level of use of 3DPT has no significant influence on the operational effectiveness of entrepreneurial companies in Jordan.

4. Research Methodology

The population examined in this study consists of the entrepreneurial industrial companies in Jordan, as the aim of the study is to examine the effects of the use of 3DPT on operational effectiveness in terms of time, cost, quality, competitiveness and management process. According to the Ministry of Industry, the number of active registered entrepreneurial industrial companies in Jordan is 672 (Ministry of Industry, 2018). Due to time and money limitations, however, a convenience sample of 224 companies (about 33% of the population of interest) located in Amman was selected for the study. Several criteria were used to ensure that respondents were qualified to provide the information sought. The first criterion was that the companies they worked for should be engaged in developing products; the second criterion was that the companies should be currently using 3DPT. A total of 224 self-administered questionnaires were distributed to respondents by e-mail and in person and the response rate was 71.8% (161 respondents).

Several variables of interest were factual (company profile details, such as size, business experience, purposes of use and type of existing 3DPT applications). In contrast, others were perceptual (extent of the use of 3DPT and operational effectiveness indicators, such as time, cost, quality, competitiveness and management). The extent of the use of 3DPT as well as various operational effectiveness indicators were measured using a Likert five-point scale that ranged from 1 = strongly disagree to 5 = strongly agree. The questions used were selected from previous studies (Schniederjans, 2017; Thompson, 2016; Steenhuis and Pretorius, 2017; Martinsuo and Luomaranta, 2018; Flores et al., 2016; Rylands et al., 2017; Khorram Niaki and Nonino, 2017). For the construct validation purpose, the questionnaire content was modified to the Jordanian business context based on the results of a pilot study and feedback from five professional academic staff in this field. When the reliability of the study was tested using the Cronbach's alpha coefficient, alpha was found to be 0.84, which suggests that the stability and consistency of the scale are acceptable (Hair et al., 2010).

4.1 Respondent Company Profiles

In this study, respondents' profiles included information about their firms' basic characteristics, such as size, business experience, experience with the use of 3DP printing technology, reasons for using 3DPT and type of 3DPT applications used.

Table 1 summarizes the respondents' profile characteristics.

Table (1)

Respondent company profiles

Respondents' Characteristics	**Frequency**	**Per cent**
Business experience		
1. (Start-up) > 3 years	2**9**	18
2. 3 - less than 6 years	**56**	34.7
3. 6 - less than 9 years	**27**	16.7
4. 9-less than 12 years	**23**	14.2
5. More than 12 years	**26**	16
Number of employees (size)		
1. 1 - 9 employees	47	29.1
2. 10 - 19 employees	56	37
3. 20 - 49 employees	21	13
4. 50 - 99 employees	17	10.5
5. 100 - 249 employees	12	7.5
6. More than 250 employees	8	4.9
Experience with using 3DP		
1. 1 - 5 years	98	60.8
2. 5 - 10 years	42	26
3. More than 10 years	21	13.2
Type of 3DPT applications*		
1. Stereolithography	79	49.1
2. Fused Deposition Modeling (FDM)	42	26
3. Binder Jetting	17	10.5
4. Multi Jet Fusion	11	4.1
5. CLIP / CDLP	8	6.8
6. Selective Laser Sintering (SLS)	19	11.8

***** *Note: Respondents can choose more than one answer.*

4.2 Descriptive Statistics

All items included in the study were tested for their means, standard deviations, skewness, kurtosis and reliability. The descriptive statistics are given in Table 2 and these indicate a positive disposition of most items. The mean values suggest a narrow spread around the mean, while the mean values of the majority of items were greater than the midpoint (3) and ranged from 3.501 to 4.08. However, after careful assessment of skewness and kurtosis, the data was determined to be normally distributed. For skewness and kurtosis, most of the values were within the appropriate ranges for normality (i.e., -1.0 to +1.0 for skewness and less than 10 for kurtosis) (Hair et al., 2017).

Table (2)
Descriptive statistics

Code	Effectiveness Indicators	Mean	SD	Skewness	Kurtosis
	Time effectiveness	3.9381	0.72262		
T1	3D printing technology has reduced the lead time.	4.0515	0.88236	-0.730	-0.037
T2	3D printing technology has reduced the time needed for prototyping cycle.	4.0412	0.90043	-1.208	1.831
T3	3D printing technology has reduced the time needed for the production cycle.	3.8557	1.14555	-1.137	0.691
T4	3D printing technology has speeded time-to-market.	3.8041	1.09582	-0.647	-0.523
	Cost-effectiveness	3.7035	0.55126		
C1	3D printing technology has reduced the cost of raw material.	3.8969	0.89541	1.17390	1.156
C2	3D printing technology has reduced the cost of tool for prototyping.	3.6289	1.20173	0.89917	-0.364
C3	3D printing technology has reduced product development cost.	4.0206	0.90115	0.80480	0.302
C4	3D printing technology has reduced the cost of maintenance.	3.6907	0.80830	0.93243	-0.909
C5	3D printing technology has reduced the cost of transportation and delivery.	3.5153	0.96617	1.07063	0.650
C6	3D printing technology has reduced the cost of labour (workers).	3.5053	1.07063	0.89292	-0.412
	Competitiveness effectiveness	3.9298	0.77930		
O1	3D printing technology has improved our competitiveness capabilities.	3.8421	0.96001	-0.973	1.354
O2	3D printing technology has seriously improved our company's market positioning.	4.0000	0.88726	-1.214	2.428
O3	3D printing technology has speeded overall business operations more effectively.	3.9474	0.87966	-1.525	3.562
	Quality effectiveness	3.8926	0.72629		
Q1	3D printing technology has increased optimization designs.	4.0842	0.094151	-1.264	1.998
Q2	3D printing technology has increased the precision and accuracy of the products' output.	3.8842	0.98783	-1.522	2.607
Q3	3D printing technology has decreased the number of assembled components for products.	3.8105	0.90265	-0.588	0.544
Q4	3D printing technology has increased the use of new ways to form materials for production (e.g. Laser, UV and Electric Beam).	3.8526	0.99966	-0.937	0.682
Q5	3D printing technology has invented a new ability to get different properties of materials.	3.8316	4.32905	-0.614	-0.460

	Management process effectiveness	3.7958	0.63311		
M1	3D printing technology has improved the management style and planning process of our company.	3.7604	.089142	-0.505	0.101
M2	3D printing technology has decreased the risks in the decision-making process.	3.8542	0.90588	-0.389	-0.183
M3	3D Printing technology has increased the privacy and security of new products in the early stages.	3.7604	1.06371	-0.886	0.465
M4	3D printing technology has increased the health and safety standard in our company (smells, heats, noise, ... etc.).	3.7396	0.95416	-0.407	-0.390
M5	3D printing technology gives our employees greater control.	3.8646	0.90169	-0.241	-0.830

4.3 The Extent of the Use of 3DPT by **Entrepreneurial** *Companies*

Table 3 presents the means and standard deviations for the five questions used to measure the extent of use of 3DP printing applications by entrepreneurs' industrial companies. The findings, as shown in Table 3, suggest a moderate uptake (75% or 3.76/5), as the mean is higher than the mean of the scale, which is 3 (mean of the scale = Σ Degrees of the scale/5 = 1+2+3+4+5 / 5 = 3). This implies that there are some variations among these industrial companies in terms of their level of use of 3DPT applications.

Table (3)

The extent of use of 3DP printing applications

Code	**Variables**	**Mean**	**SD**
1	The company has fully integrated 3D printing technology in its business plan operations.	3.5876	.99742
2	The company has entirely invested in IT infrastructure to adopt 3D printing technology.	3.7835	1.05304
3	The company has 3DPT experts available to deploy 3D printing technology fully.	3.8041	1.09582
4	The company top management has fully supported the decision to adopt 3D printing technology.	4.0825	0.87405
5	The company has adopted 3D printing technology in its manufacturing operations completely.	3.5567	0.88939
	Average	3.7629	0.69482

5. Hypotheses Testing Results

ANOVA was used to examine the first two hypotheses (Ho1 and Ho2). It was used to assess the level of differences among entrepreneurs' company group means in terms of using 3DPT based on their size and business experience. One-way analysis of variance (ANOVA) was used to compare the means of participants' extent of 3DPT and to determine whether there are any significant differences among the entrepreneurs' companies due to their number of employees (size) and number of years in business (experience).

Table 4 summarizes the results of ANOVA. The results indicate that the level of the extent of using 3DPT significantly varied among entrepreneurial' companies due to their size and business experience. These results indicate that entrepreneurs' size and business experience play significant roles in their extent of using 3DPT applications in Jordan.

Table (4)
The ANOVA results for hypotheses Ho1 and Ho2

Characteristics		Sum of Squares	Df	Mean Square	F	Sig.
Ho1: Size	Between Groups	8.608	3	33.404	3.800	0.014
	Within Groups	231.356	156	2.113		
	Total	239.964	159			
Ho2: Business experience	Between Groups	11.710	3	36.357	4.208	0.001
	Within Groups	265.210	156	3.424		
	Total	276.920	159			

Multiple regression analysis techniques were used to examine the 3rd hypothesis. The level of significance was chosen as 0.05, hence a 95% level of confidence. Table 5 summarizes the results of multiple regression analysis based on the F-ratio test for the above hypothesis. The results indicate that there is a significant and positive influence of adopting 3DPT by entrepreneurial companies on their operational effectiveness indicators (time, cost, competitiveness, quality and management) examined as a whole. The R-square result also indicated that the extent of use of 3DPT could explain 39.8% of the variation in operational effectiveness. The hypothesis is thus not rejected.

Table (5)
Multiple regression for the third hypothesis

Hypothesis	Multiple R	R-square	Adjusted R-square	DF	F	Sig.
Ho3	0.631	0.398	0.364	5	11.758	0.000

Using a stepwise multiple regression method, the indicators of operational effectiveness most highly correlated with the use of 3DPT are expected to enter the regression equation. The F value at the 0.00 level of significance is used to determine the "goodness of fit" for this regression equation; this is the ratio of explained to unexplained variance as presented by the regression equation, where the total variance represents a low ratio and the interpretation of the individual beta coefficient has little meaning (SPSS, 2016). Therefore, when the adjusted R-square is about 0.10 or higher and the F value of the regression equation reached 0.05 significance, the individual beta weight was determined before interpreting the results of multiple regression analysis and the degree of multicollinearity were tested by examining the relative size of the pairwise correlation coefficient between independent explanatory factors. An examination of the correlation matrix indicates that the correlation for each coefficient is less than 0.50. Therefore, the findings are plausible, as the multicollinearity is not severe (Hair et al., 2010). Hair et al. (2010) suggested also assessing the tolerance and variance inflation factor (VIF). Tolerance refers to the assumption of variability in one independent variable that does not explain the other independent variable and VIF explains much of the same information. The common cut-off threshold is a tolerance value of 0.10, which corresponds to a VIF value above 10. Multicollinearity is indicated at a tolerance level of less than 0.10 or a VIF value above 10. The tolerance value for each independent variable was above the ceiling tolerance value of 0.10, consistent with the absence of severe levels of multicollinearity. This judgment was further supported by the VIF value for each independent variable being above the threshold value of 1.0. Table 6 shows more details.

Table (6)
Collinearity diagnostics

Effectiveness Indicators	Tolerance	VIF
Time	0.846	1.182
Cost	0.816	1.226
Quality	0.599	1.669
Competitiveness	0.520	1.922
Management process	0.504	1.985

The results of calculating the beta coefficients are given in Table 7; these indicate that the operational effectiveness indicators most highly associated with the use of 3DPT are times cost and quality. It can be concluded that the higher the use of 3DPT, the higher these operational effectiveness indicators will be. Therefore, entrepreneurs should fully utilize and ingrate 3DPT in their business processes in order to enhance those effectiveness measures.

Table (7)
Stepwise regression analysis results

Indictors	Step	R	R-square	Adjusted R-square	Beta	Sig.
Time	1	0.498	0.248	0.240	0.450	0.000
Cost	2	0.577	0.332	0.318	0.336	0.000
Quality	3	0.609	0.371	0.351	0.208	0.020

6. Discussion of Results

The purpose of this study was to examine the effects of the use of 3DPT applications on the operational effectiveness indicators in Jordanian entrepreneurs' companies (time, cost, quality, competitiveness and management process). In order to achieve the study objectives and to conduct the research systematically, several hypotheses were developed and tested. The results indicated that the extent of 3DPT applications being used by entrepreneurs' companies was considered moderate (0.76). This result agrees with prior studies, such as those by (Guo and Leu, 2013; Flores et al., 2016; Thompson, 2016; Steenhuis and Pretorius, 2017; Rylands et al., 2017; Khorram Niaki and Nonino, 2017; Martinsuo and Luomaranta, 2018). The potential benefits of the use of 3DPT applications for entrepreneurs' companies include developing competitiveness and improved cost, time and quality processes for their products and management (Ford and Despeisse, 2016). The results also indicated that the extent of using 3DPT among the study respondents was varied not only due to their size (number of employees), but also due to their number of years in business. It was indicated that entrepreneurs' companies with large sizes and long experience were more inclined to use 3DPT. This might be because the majority of respondents (see Table 1) have only recently adopted 3DPT and are still in the early stages of that use.

The analysis also provided empirical evidence for the effect of adopting 3DPT applications on operational effectiveness indicators in the primary hypothesis (time, cost, quality, competitiveness and management process). The results support the linkage between 3DPT utilization and operational effectiveness indicators when examined as a whole. The results also suggest that the extent of use of 3DPT can explain about 39% of the variation in operational effectiveness indicators. This result is supported by Schniederjans (2017) and Steenhuis and Pretorius (2017). Further, the stepwise regression analysis results indicated that the most important types of operational effectiveness indicators highly associated with the use of 3DPT were time, cost and quality. This result validates and supports the value triangle theory based on these three interrelated effectiveness indicators: time, cost and quality. Thus, entrepreneurs should fully utilize and integrate 3DPT into their business processes in order to improve their operational effectiveness, particularly about those three measures.

7. Contributions and Managerial Implications

This study and its findings make several contributions and have several implications. The research is built on relevant published work and empirical surveys to investigate the impact of the use of 3DPT on operational effectiveness in entrepreneurial companies. Reviewing the existing literature revealed that similar studies had not previously been undertaken on Jordanian entrepreneurs' companies. In addition to the contribution of this study to theoretical development, the useful findings produced can be utilized by entrepreneurial managers in Jordan to support the development and implementation of practices that will lead to full utilization of 3DPT in their companies' manufacturing processes.

The theoretical implications of this study are fourfold. The findings of this study contribute to the literature on 3DPT utilization which can be used to improve operational effectiveness. This study contributed to the 3DPT literature by integrating and examining the five most common operational effectiveness measures as related to the extent of use of 3DPT for the first time in a Jordanian business context. The results of this study can thus aid managers in comprehending how 3DPT can improve operating process effectiveness and business effectiveness, as entrepreneurs can search for and adopt tools that can increase the use of 3DPT applications if they wish to improve operational effectiveness.

There are also significant implications from this study's findings for entrepreneurs, managers, practitioners and other decision-makers in similar organizations. Decision-makers should be fully aware of the importance of the effect of 3DPT applications on their operating processes and business effectiveness, in order to make the right decisions and choose the right direction for any changes within their organizations. Also, the role of 3DPT applications in enhancing a company's operational effectiveness should be considered when making strategic choices for the future in every organization.

Despite the valuable insights this study has provided, several limitations exist. However, it brings about several future research avenues that appear worthy of future examination. First, the integrated model of the study implies the future space for adding other operational effectiveness indicators, either subjective or objectives. Second, considering that this research focuses on Jordan, to generalize the results, future research is warranted in other countries. Third, it would be interesting to test the proposed model in other environmental contexts. This study is aimed at entrepreneurs' companies; future studies may focus on other business sectors.

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