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Additive manufacturing in the wood-furniture sector: Sustainability of the technology, benefits and limitations of adoption

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Abstract

Purpose – In the world economy there is the emergence of advanced manufacturing technologies that are enabling more cost and resource-efficient small-scale production. Among them, additive manufacturing, commonly known as 3D printing, is leading companies to rethink where and how they conduct their manufacturing activities. The purpose of this paper is to focus in the Italian wood-furniture industry to understand if the companies in this sector are investing in additive manufacturing techniques, to remain competitive in their reference markets. The research also attempts to investigate the potential sustainable benefits and limitations to the implementation of 3D printing in this specific sector, considering the companies that have already implemented this technology.

Design/methodology/approach – Data were collected using a structured questionnaire survey performed on a sample of 234 Italian companies in this sector; 76 companies claimed to use 3D printing in their production system. The questionnaire was distributed via computer-assisted web interviewing and it consisted of four sections.

Findings – The research has highlighted how Italian 3D companies have a specific profile; they are companies aimed at innovating through the search for new products and product features, putting design and Made in Italy in the first place. They pay high attention to the image they communicate to the market and are highly oriented to the final customer, and to the satisfaction of its needs.

Originality/value – The study is attempting to expand a recent and unexplored research line on the possible advantages and disadvantages of the implementation of emerging production technologies such as 3D printing.

Keywords Innovation, 3D printing, Additive manufacturing, Industry 4.0, Advanced manufacturing technology

Paper type Research paper

1. Introduction

Currently the world economy is going through a period of transition and change in the manufacturing landscape. Jeremy Rifkin believes that the phase of digitization, the third, has just begun and has yet to fully show all its implications and its potential (Rifkin, 2011).

On the contrary Klaus Schwab, a German Engineer and Economist, best known as the Founder and Executive Chairman of the World Economic Forum, argues in his book *The Fourth Industrial Revolution*, that the first three revolutions are the transport and mechanical production revolution of the late eighteenth century; the mass production revolution of the late nineteenth century, and the computer revolution of the 1960s. He agrees that some people might consider the fourth revolution just an extension of the third but claims that the scale, speed and impact of the latest technologies deserve a revolution of their own (Schwab, 2016).

Whether the revolution in act today is the Third or the Fourth, it can be said that one of the most significant drivers of this change is the emergence of advanced manufacturing technologies that are enabling more cost- and resource-efficient small-scale production. In combination with other prominent trends such as servitisation (Neely, 2008), personalization (Zhou *et al.*, 2015) and prosumption (Fox and Li, 2012), the emergence of

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Additive Manufacturing (AM), commonly known as 3D printing, as a direct manufacturing process, is leading companies to rethink where and how they conduct their manufacturing activities (Ford and Despeisse, 2016).

AM is defined as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining" (ASTM, 2010). The 3D printing process works as follows. Once the user has selected an electronic design blueprint and loaded up the raw materials into the 3D printer, the machine begins its work. In a process that can take several hours to days, the 3D print head deposits layer upon layer of tiny droplets of raw material to form the object. Depending on the complexity of the design, the machine is able to switch between different print heads to work with multiple materials and form shapes with a number of colors and diverse textures. Eventually, after countless back-and-forth sweeps, a three-dimensional object forms out of the raw material (Lipson and Kurman, 2010).

This technology evolved during the mid-1980s when computing and control systems progressed (Hopkinson *et al.*, 2006); in its early years AM was mostly applied for the fabrication of conceptual and functional prototypes, which is also known as rapid prototyping (Mellor *et al.*, 2014).

Only recently 3D printing has gained much attention, as the process has proven to be compatible with industrial manufacturing beyond prototyping (Berman, 2012; Gershenfeld, 2012; Reeves, 2008). Therefore the concept of rapid manufacturing (RM), a production of end-use parts from AM systems (Hague *et al.*, 2004), emerged in the last decade; though its economic impact has remained modest (Levy *et al.*, 2003). Bai *et al.* (2017), employed a patent bibliometric analysis and found that at the moment the USA, Japan, and Germany are the leading countries in 3D printing technology, although the technology accumulation patterns of these countries are rather different. Additionally Israel and Italy also have good performance in the fast-growing technology sub-fields.

The most commonly applied processes are Stereolithography (SLA), selective laser sintering (SLS), digital light processing, fused deposition modeling, selective laser melting and electron beam melting (Petrovic *et al.*, 2011). Although the technologies have many similarities as their development was simultaneous there are also distinct differences between each one (Kulkarni *et al.*, 2000). Reviews of the numerous AM technologies have been performed in previous works (Gibson, 2010; Groover, 2007; Hopkinson *et al.*, 2006). Polymers, alloys of aluminum, steel and titanium, as well as ceramic composites are currently printable at a minimum layer thicknesses of 20-100 μm, depending on the process and the physical state of the material (Hopkinson *et al.*, 2006). Therefore, 3D printing can be applied to various manufacturing markets. The decision to invest in additive manufacturing technologies must be linked to the market and product characteristics. Generally, the product characteristics are: products with a degree of customization; products with increased functionality through design optimization and those of low volume (Mellor *et al.*, 2014).

The aim of the research is to focus on the Italian wood-furniture industry and to understand if the companies in this sector are investing in digital technologies particularly in AM techniques, in order to remain competitive in their reference markets. The research also attempts to investigate the potential sustainable benefits and limitations of implementing AM in this specific sector.

It has been decided to focus the research on this sector as the Italian furniture industry is one of the solid pillars of Made in Italy, and is known and appreciated in all international markets, with more than 40 industrial districts. Available data on this sector show that two of the three major European furniture producing regions are Italian (Veneto and Lombardy), and among the top 15, are other three Italian regions, Marche, Friuli Venezia Giulia and Tuscany. Globally, this sector is second only to China for trade surplus, and owing to its manufacturing skills it generates an added value of 4.9 billion Euro. This is far greater than the many countries naturally rich in woody raw materials, such as France, Spain and Sweden (GreenItaly, 2016). Moreover, enterprises in this sector are defined by Borga *et al.* (2009) as extremely flexible in adapting to the requirements of the market and they have a direct relationship with the customer.

The research questions, investigated by this paper are the following:

RQ1. What is the extent to which Additive Manufacturing is adopted in the Italian wood-furniture industry and how much these companies are investing in it to remain competitive in their reference market?

RQ2. Which are the sustainability benefits perceived by those companies that adopt AM technologies?

RQ3. Which are the main limitations perceived by those companies that adopt AM technologies?

The paper seeks to develop a research line recently undertaken by authors such as Berman (2012), Ford (2014), Ford and Despeisse (2016), Gebler *et al.* (2013). The analysis of the Italian context, could be taken as a reference for the companies that operate in the same industry in other developed countries.

The paper is divided as follows: Section 2 investigates the literature panorama on additive manufacturing; Section 3 defines the methodology developed for the empirical research; Section 4 presents the results of the research and discusses them with other international works. Finally the conclusion section, defines practical implications and limitations and future research directions.

2. Literature panorama on additive manufacturing

2.1 Development of AM technologies

From a review of the US patent literature, Bourell *et al.* (2009) identified two early roots of the modern AM technique: topography and photosculpture which date back almost 150 years. Both of these early technologies might be categorized as manual "cut and stack" approaches to build a freeformed object in a layerwise fashion.

However the first attempt to modern AM was made in 1956 from the mind of John Munz, who developed a method to "register" solid objects in a resin. Munz (1956) proposed a system that has features of present day stereolithography techniques. Subsequently in 1968, Swainson (1977) proposed a process to directly fabricate a plastic pattern by selective, three dimensional polymerization of a photosensitive polymer at the intersection of two laser beams, while Ciraud (1972) proposed a powder process that has all the features of modern direct deposition AM techniques. The real AM technique first emerged with Stereolithography (SL) from 3D systems, a process that solidifies thin layers of ultraviolet (UV) light sensitive liquid polymer using a laser. All was set in motion in 1984 when Charles Hull, cofounder and chief technical officer of 3D systems, applied for a US patent titled Apparatus for Production of Three Dimensional Objects by Stereolithography, which was granted in March 1986 (Hull, 1986). The following year after the SL patent of 1986, 3D system produced the first SL 3D printer machine, and the first SLS machine later in the year. This machine was similar to SL technology but used a combination of powder and laser instead of a liquid. This defined the advent of the development of AM technologies.

Early AM technologies were built around materials that were already available and had been developed to suit other processes. However, the AM processes are somewhat unique and these original materials were not ideal for these new applications. Therefore, as technology was understood better, materials were developed specifically to suit more closely the operating parameters of the different AM processes (Gibson *et al.*, 2010). With some of the AM processes there is the potential to mix and grade materials in any combination that is desired, thus enabling materials with certain properties to be deposited where they are needed (Anon, 2001; Jacobs, 2002). The overmoulding technique is a classic example of how design can be influenced by the availability of a manufacturing technique; it allows designers, within certain limits, to produce parts that have added functionality and enhanced design (Hague *et al.*, 2003).

Regarding the costs of the materials used for AM, analyses (Hopkinson and Dickens, 2003; Atzeni *et al.*, 2010) put material cost at around 30 percent of the unit cost for AM systems compared with an almost inconsequential amount (0.2-2.7 percent) for traditional methods. Differences in this regard are largely due to the extreme cost differentials that exist in the market between AM and more traditional material feedstock; it is 100 times costlier than commercial grade (Cotteleer, 2014).

Material recyclability drives cost as well. Assumptions of zero waste in AM applications seem inappropriate. Consensus on the amount of unprocessed material that can be recycled is hard to find. Some cite zero reuse for highly sensitive aerospace applications, while others suggest near-total reuse is possible (Allen, 2006; Telenko and Seepersad, 2012). Material recycle rates vary by process, system, and application and should be carefully evaluated as part of the business case (Hopkinson and Dickens, 2003).

2.2 Economic, environmental and organizational implications

The adoption of AM and other advanced manufacturing technologies appears to herald a future in which value chains are shorter, smaller, more localized, more collaborative, and offer significant sustainability benefits (Gebler *et al.*, 2013). As stated by Ford and Despeisse (2016), among the many potential sustainability benefits of this technology, three stand out: improved resource efficiency, extended product life and reconfigured value chain. It is important to underline that sustainability capability in manufacturing can be defined as the ability to combine manufacturing practice with operational practices in design, distribution, use, product service, and governance for innovative and marketable combinations of products and services that contribute to sustainability (Holmström *et al.*, 2017), in an economical, environmental and social way.

Focusing on the economic and environmental implications of this technology, Rylands *et al.* (2016) found that the implementation of AM can cause a shift in value propositions and the creation of additional value streams. It may also significantly reduce the need for large inventory, which is a significant cost in manufacturing. In 2011, there was an average of $208 billion or the equivalent of 14 percent of annual revenue held in inventory for medium- and high-tech manufacturing with an estimated cost of $52 billion or 3 percent of revenue. Reducing inventory frees up capital and reduces expenses (Thomas and Gilbert, 2014).

Life cycle analyses have shown that the adoption of AM could have significant savings in the production of goods (Birtchnell and Urry, 2016). Savings are estimated at $113-370 billion by 2025, with these arising from reductions in material inputs and handling (Gebler *et al.*, 2013). 3D printing lowers manufacturing-related resource inputs as it solely requires the amount of material which ends up in the printed good without too many losses. Support materials can usually be reused (Reeves, 2008; Huang *et al.*, 2013). There is also potential for recycling both the excess materials and existing objects once formed. In 2015 Dutch start-up company Refil launched their fully recycled plastic filament wire made from shredded Volvo and Audi cars (Birtchnell and Urry, 2016).

Energy consumptions is another important factor of sustainability in considering AM compared to other methods of manufacturing, especially in terms of examining the costs from cradle to grave. Energy studies on AM, however, tend to focus only on the energy used in material refining and by the AM system itself (Hopkinson and Dickens, 2003; Baumers *et al.*, 2012; Morrow *et al.*, 2007; Telenko and Seepersad, 2012).

Moreover 3D printing generates shifts in labor patterns, as the process is highly automated and only requires human workforce in pre- and post- processing (Lindemann *et al.*, 2012; Petrovic *et al.*, 2011). Labor-related implications show different patterns in developed and developing countries. The high degree of automation could be economically beneficial for developed countries with ageing societies, but destabilize developing countries if the production volumes re-shift to consumer countries (Campbell *et al.*, 2011). Open source-based applications of 3D printing could contribute to a sustainable development in rural areas with low economic profiles, as 3D printing bridges the spatial gap to the next market of spare parts, consumer products or tools (Pearce *et al.*, 2010).

Another important impact could be company culture (Hopkinson *et al.*, 2006). Using AM processes as a manufacturing technology requires designers and engineers to rethink design for manufacturing (DFM). DFM is any aspect of the design process in which the issues involved in manufacturing the designed objects are considered explicitly with a view to influencing the design. AM requires users to match product with process and to understand new technology process capabilities. Hence the workforce experience and skill is a key factor in AM implementation.

Moreover, the design freedoms offered by AM allow product and component redesign. Several parts made of various materials can be replaced by one integrated assembly, which will reduce or eliminate cost, time and quality problems deriving from assembling operations (Ford, 2014; Ford and Despeisse, 2016).

Furthermore with geometric freedom, AM allows products to be produced using less material while maintaining the necessary performance. In terms of materials, metal and plastic are primarily used for this technology. However, they are not necessarily greener than materials used in traditional manufacturing. The one exception may be the bio-polymer polylactic acid (Faludi *et al.*, 2015). The cost of material for AM can be quite high when compared to traditional manufacturing. Atzeni and Salmi (2012) showed that the material costs for a selected metal part made from aluminum alloys was €2.59 per part for traditional manufacturing and €25.81 per part for AM using SLS; thus, the AM material was nearly ten times more expensive. The material costs of AM are significant; however, technologies can be complementary, in the sense where adopting two technologies alongside each other would result in greater benefits than if they were adopted individually (Reeves, 2008; Thomas and Gilbert, 2014). Therefore machines and materials for AM are still expensive but the cost of these will decrease as AM becomes a more commonly used production technique. Furthermore, AM is expected to become more cost effective as larger production volumes become more economically feasible than at present (Ford and Despeisse, 2016).

AM can also bring some changes in the supply chain of a company. The supply chain includes purchasing, operations, distribution, and integration. Purchasing involves sourcing product suppliers. Reducing the need for these activities can result in a reduction in costs (Reeves, 2008).

Furthermore, supply chains shift from physical goods to digital ideas/designs (Campbell *et al.*, 2011). This shift increases supply chain dynamics by reducing the "time-to-market" (Petrovic *et al.*, 2011) and induces a further relative decline in imports/exports (Campbell *et al.*, 2011). Exports are projected to shift back to consumer countries as 3D printing reduces the labor cost-related comparative advantage of countries such as China and the technological advantage of countries of Germany or Japan (Campbell *et al.*, 2011). Global supply chains are further expected to relatively shift from final products to raw materials as goods manufacturing becomes more localized while material raw production is spatially bound to its reserves (Campbell *et al.*, 2011). Lastly, supply chains are expected to become less transport intensive (Birtchnell and Urry, 2013). AM allows for the production of multiple parts simultaneously in the same build, making it possible to produce an entire product. Traditional manufacturing often includes production of parts at multiple locations, where an inventory of each part might be stored. Thomas and Gilbert (2014) summarize three different alternatives for AM, defining a fourth one. The first is where a significant proportion of consumers purchase AM systems or 3D printers and produce products themselves (Reeves, 2008). The second is a copy shop scenario, where individuals submit their designs to a service provider that produces goods (Neef *et al.*, 2005). The third scenario involves AM being adopted by the commercial manufacturing industry, changing the technology of design and production. They consider a fourth scenario: since AM can produce a final product in one build, there is limited exposure to hazardous conditions, and there is little hazardous waste (Huang *et al.*, 2013). For this reason there is the potential to bring production closer to the consumer for some products (Holmström *et al.*, 2017).

Mellor *et al.* (2014) stated that analyzing organizational implications of this new manufacturing technology, for the adopting organization to gain competitive advantage from the implementation of AM its ability to link the technology benefits to the business strategy has to be emphasized. The size of an organization has been identified to be critical to the understanding of the process of implementation of new manufacturing technologies. Many authors have suggested small businesses cannot be considered scaled-down to larger ones, and the theories proved large enterprises might not be suitable for small business (Federici, 2009; Schubert *et al.*, 2007). The approach in implementing a SME is likely to be different to that in a large multinational company. Linked to size, previous studies of new manufacturing technology implementation suggest that the structure of an organization is the key factor to successfully implement manufacturing technology (Ghani *et al.*, 2002; Saberi *et al.*, 2010), and that companies that adopt without first re-designing organizational structures and processes encounter high difficulties (Saberi *et al.*, 2010). Therefore, it is proposed for successful implementation of AM technologies that the decision to adopt is accompanied by a change in jobs and tasks, and thus a change in work practices and structure.

3. Methodology

3.1 Sampling and data collection

Data were collected using a questionnaire survey performed on a sample of $n = 2{,}035$ Italian companies which operate in the wood-furniture industry, using simple random sampling. The survey began January 26th, 2017 and answers were accepted until February 28th, 2017. The administration of the survey took place by e-mail; 234 companies participated in the survey. A structured questionnaire was distributed via computer-assisted web interviewing consisting of four sections. Section 1 investigated the sample profile of the respondent companies, the factors in which they pay attention to the development of their products, whether or not they produce prototypes in their company and their knowledge and use of 3D printers. Section 2 was reserved to the companies that know and use 3D printers in their production process, and it asked them to assess the perceived benefits of this technology, and evaluate the possible limitations of implementing it. Section 3 was dedicated to companies that know 3D printing but have never used this technology (neither internally nor externally), and the reasons why they have never approached to this technology were evaluated. Finally, Section 4, is a conclusive section that evaluate the level of adoption of this technology in the company supply chain, if companies perceive some dangers related to this additive technology, and the importance of investing in digital technologies.

3.2 Measurement validation

Descriptive analysis was performed to describe the sample profile of respondent companies. A five-point Likert scale was used to evaluate companies' attitudes and behaviors and perceived benefits and limitations of implementing AM technologies. To verify the reliability of the Likert analysis, Cronbach's α values were computed, taking into account only α values greater than 0.60 as suggested by Nunnally and Bernstein (1994). A principal component analysis (PCA) followed by Oblimin rotation (Jennrich and Sampson, 1966) was applied to the items related to benefits and limitations of adopting AM technologies and to factors related to what kind of products companies are willing to realize with AM. The PCA, an optimal dimensionality reduction technique in terms of capturing the variance of the data (Russell *et al.*, 2000), facilitated the summarization of group companies' main perceived benefits and limitations to the implementation of AM in this sector and also understanding their orientation in productive terms through the use of AM technologies.

In the estimation data process, the variables with factor loadings less than 0.60 were dropped from further analysis, because they were not considered statistically significant.

4. Results and discussion

4.1 Sample profile

Among the whole sample of respondent companies ($n = 234$), the paper will focus on analyzing the behavior of those 3D printing technologies, internally or externally, called "3D companies." In detail, 19.3 percent of respondents declared to use internally these technologies and 13.2 percent to use them externally. A total of 76 companies were taken as reference sample.

Defining the profile of 3D companies (Table I), the majority are of small (30.3 percent) and medium (43.4 percent) size, with a turnover between 2 and 50 million of Euro. They are mainly located in the Northern and Central regions of Italy, that are the most economically developed and 89.5 percent of them have reference markets as the international ones.

	All sample $n = 234$		3D companies $n = 76$ (32.5%)	
	n	%	*n*	%
Dimension				
Micro	25	10.7	4	5.3
Small	101	43.2	23	30.3
Medium	79	33.8	33	43.4
Large	29	12.4	16	21.1
Turnover (€)				
Less than 2 Mln	41	17.5	4	5.3
2-10 Mln	84	35.9	21	27.6
11-50 Mln	77	32.9	34	44.7
More than 50 Mln	32	13.7	17	22.4
Regions				
North	124	53.0	43	56.6
Center	106	45.3	31	40.8
South and Islands	4	1.7	2	2.6
Reference markets				
Italy	14	6.0	3	3.9
Italy and Europe	30	12.8	5	6.6
International markets	190	81.2	68	89.5
Price range				
Low	0	0.0	0	0.0
Lower-middle	10	4.3	1	1.3
Medium	48	20.5	9	11.8
Upper-middle	141	60.3	50	65.8
High	35	15.0	16	21.1

Table I. Sample profile of the respondent companies

Regarding the type of products they sell, the respondent companies declared to realize products in the upper-middle (65.8 percent) or even high (21.1 percent) range.

Table II shows the areas of specialization of companies that participated in the survey within the wood-furniture industry. In the whole sample the majority of respondents work in the accessories sector (13.7 percent), followed by those producing office furnishings (12.0 percent), kitchen furnishings (11.1 percent) and bathroom furnishings (9.4 percent). 3D printing technologies are used mainly by those manufacturing accessories (18.4 percent) and those producing bathroom (13.2 percent) and office (13.2 percent) furnishings. On the contrary among the sectors in which AM techniques are not considered at all there are outdoor furnishings, mattresses, school furnishings and semi-finished products. Therefore there seems to be a high degree of heterogeneity in the use of these technologies within the same reference industry, depending on the manufactured products.

4.2 Wood-furnitures companies' attitudes and behaviors

First 3D companies were asked, what percentage of their total production (including prototyping) is made in 3D. The 72.4 percent of respondents declared to have started using it in a small scale, in only 10 percent of their total production; the 15.8 percent make from 11 to 50 percent of their total production with 3D printings and only 11.8 percent of them produce more than 50 percent of their production using AM techniques.

Second, analyzing companies' attitudes and behaviors, it can be seen that they give high importance to all the aspects defined in Table III, even if in particular to the creation of modern and innovative products with high design (4.79), which meet the standards of "Made in Italy" (4.70) and they pay high attention to the image they communicate to customers (4.79). Furthermore the enhancement of the brand as a source of competitiveness on the market (4.61) and the use of materials of quality for the realization of their products (4.61) are considered as very important.

4.3 Benefits and limitations of additive manufacturing implementation

Subsequently the main benefits and limitations of using AM techniques have been investigated.

Table II. Wood-furniture sectors of respondent companies

	All sample $n = 234$		3D companies $n = 76$ (32.5%)	
	n	%	n	%
Accessories	32	13.7	14	18.4
Furnishings for bars and shops	15	6.4	6	7.9
Classic furnishings	13	5.6	3	3.9
Outdoor furnishings	4	1.7	0	0.0
Bathroom furnishings	22	9.4	10	13.2
Bedroom furnishings	11	4.7	6	7.9
Collectivity	15	6.4	5	6.6
Kitchen furnishings	26	11.1	6	7.9
Domestic multiproducts	16	6.8	6	7.9
Upholstered furnishings	14	6.0	5	6.6
Mattresses	1	0.4	0	0.0
Panels	5	2.1	1	1.3
School furnishings	3	1.3	0	0.0
Semi-finished products	18	7.7	0	0.0
Living room furnishings	7	3.0	2	2.6
Office furnishings	28	12.0	10	13.2
Other	4	1.7	2	2.6

	3D companies $n = 76$ (32.5%) Mean	SD
Creation of customized products	4.50	0.721
Creation of modern and innovative products with high design	4.79	0.442
Creation of quality products that meet the standards of the "Made in Italy"	4.70	0.542
Creation of sustainable products	4.18	0.725
The quality of the materials used for the creation of products	4.68	0.518
The enhancement of the brand to be competitive on the market	4.68	0.571
The image of the company communicated to customers	4.79	0.442

Note: Cronbach's α 0.748

Table III. Companies attention paid to these business practices

Regarding main advantages (Table IV) experienced from companies in the wood-furniture industry, the reduction in time for prototyping is most perceived in terms of importance (4.53), followed by the reduction in time to define technical specifications of products (4.09) in line with the studies of Petrovic *et al.* (2011) and Ford and Despeisse (2016). 3D companies have also strengthened the ability of AM techniques to create products with complex geometries, increased performance and quality (4.05), as underlined by Hopkinson *et al.* (2006) and Ford and Despeisse (2016), suggesting that the freedom of design of AM techniques allow to redesign the whole product and its components, eliminating assembling problems related to cost, time and quality. These results are also found in the aircraft industry, where AM helps to manufacture high complex parts and permits to develop new engineering possibilities, due to the ability to convert structurally optimized geometries and bionic structures without adaptation into the part of the design, which results in extremely strong lightweight designs (Emmelmann *et al.*, 2011).

Two further important elements perceived are the reduction in time to market (3.82) and in production time (3.42). This is confirmed by the work of Petrovic *et al.* (2011), which

	3D companies $n = 76$ (32.5%) Mean	SD
Reduction in time to define technical specifications of products	4.09	0.786
Reduction in prototyping time	4.53	0.642
Reduction in production time	3.42	1.074
Reduction in time to market	3.82	0.795
Reduction in costs of materials	2.99	1.149
Reduction of inventory and unsold costs	2.21	1.123
Reduction in transport costs	2.16	1.132
Reduction of labor costs	2.75	1.297
Energy saving	2.64	1.116
Creation of new products with complex geometries, increased performance and quality	4.05	1.082
Creation of a new business model: offer of a virtual model	2.67	1.331
Greater chance of internationalization	2.53	1.238
Shift of production to retail outlets	1.93	1.075
Product customization	3.34	1.302
Ability to co-design with the customer	2.83	1.360
Reduction in environmental impact	2.74	1.300
Ability to serve niche markets	2.92	1.374

Note: Cronbach's α 0.928

Table IV. Perceived benefits from 3D printing use claimed that AM will increase supply chain dynamics, and therefore at the same time will also create a relative decline in imports/exports (Campbell *et al.*, 2011).

On the contrary among the less important benefits considered there is the shift of production to retail outlets (1.93), followed by the reduction in transport costs (2.16) and in inventory and unsold costs (2.21). This is in contrast with the findings of Birtchnell and Urry (2013), which was that supply chains are expected to become less transport intensive and Thomas and Gilbert's (2014) finding that AM reduces the need for large inventory. Kothman and Faber (2016) through a study in the construction industry also found that 3D printing not only shortens lead times and reduces material usage, but also reduces logistical and production efforts.

As for the disadvantages in using 3D printings (Table V), there are no relevant ones perceived, in fact the lack of staff training (3.04) and the investment in 3D printing was considered excessively high slightly exceeding the threshold of indifference (value 3) and viewed as the two most relevant ones. As stated in literature (Ghani *et al.*, 2002; Saberi *et al.*, 2010), for successful implementation of AM technologies, the decision to adopt them has to be accompanied by a change in jobs and tasks, and also in work practices and structure, however the investment needed is not considered a constraint to their implementation.

Moreover this technology does not seem to be perceived as unsuitable for this specific industry, therefore wide spreading margins of AM techniques could be possible.

When considering the type of 3D printings companies can have (Table VI), it can be seen that these technologies are clearly used almost completely for prototyping (Mellor *et al.*, 2014; Santos *et al.*, 2006), even if the standard deviation of the items "small finished product series" and "customized products" seem to define that a small percentage of these companies are also trying to create small product series and products that are totally created on customer needs. Therefore, companies that are using this technology are starting to understand that AM has the potential to bring production closer to the consumer (Holmström *et al.*, 2017). This is still a developed phenomenon in other sectors, for example the dental one, where Deradjat and Minshall (2017) found that RM can enable mass

Table V. Perceived limitations from 3D printing users

	3D companies $n = 76$ (32.5%)	
	Mean	SD
Technology is not suited to the wood-furniture sector	2.61	1.287
Lack of interest in the market	2.59	1.180
Lack of knowledge of potential benefits and problems	2.83	1.182
Lack of staff training	3.04	1.194
Excessively high investment	3.03	1.107

Note: Cronbach's α 0.683

Table VI. Willingness to create with 3D printing

	3D companies $n = 76$ (32.5%)	
	Mean	SD
Prototypes	4.59	0.593
Small finished product series	2.50	1.456
Customized products	2.51	1.419
Eco-sustainable products	2.30	1.395

Note: Cronbach's α 0.775

customization in manufacturing by achieving both a high number of units produced and as well as a high level of customization of each product.

After performing a PCA of variables which were positively influenced by the use of 3D printings, three main components emerged (Table VII). The first one in terms of importance with a cumulative variance of 67.24 percent is called design and customization and it includes benefits related to the possibility to create products with free forms and complex geometries with reduced time and high performance and the possibility to create products that completely satisfy customers' needs (Hague *et al.*, 2003; Hopkinson *et al.*, 2006; Holmström *et al.*, 2017).

The second component named time and material reduction explained 59.79 percent of cumulative variance, and refers to benefits related to time spare in the definition of technical specifications and prototyping but also in cost saving for materials used, since AM does not operate in a subtractive manner as in the traditional production system (Beltrametti and Gasparre, 2015). Finally the third component, named sustainability and competitiveness (47.57 percent of cumulative variance), concerns factors related to new market strategies, more internal efficiency and reductions in environmental impacts, supporting the theory of Gebler *et al.* (2013) which views that these new technologies offer a future in which value chains are shorter, smaller, more localized, more collaborative, and offer significant sustainability benefits.

Subsequently, after performing the PCA on factors that could affect the use of AM technologies, three main component emerged (Table VIII). The most relevant one (cumulative variance of 46.37 percent) is called unsuitability, and it is related to the belief that the technology is not suited for the wood-furniture industry and that there is no interest for it in this market. The second component in terms of relevance, is named knowledge and training and has a cumulative variance of 24.88 percent, which explains that sometimes a

	Pattern matrix[a]		
	Sustainability and competitiveness	Time and material reduction	Design and customization
Reduction in time to define technical specifications of products	0.132	*0.801*	−0.244
Reduction in prototyping time	−0.240	*0.735*	0.185
Reduction in production time	0.325	0.559	0.232
Reduction in time to market	−0.135	0.484	0.558
Reduction in costs of materials	0.415	*0.661*	−0.084
Reduction of inventory and unsold costs	*0.922*	0.010	−0.084
Reduction in transport costs	*0.882*	0.039	−0.100
Reduction of labor costs	*0.608*	0.166	0.078
Energy saving	*0.808*	0.021	0.035
Creation of new products with complex geometries, increased performance and quality	0.161	0.007	*0.644*
Creation of a new business model: offer of a virtual model	*0.799*	−0.058	0.124
Greater chance of internationalization	*0.728*	0.024	0.292
Shift of production to retail outlets	*0.947*	−0.005	−0.205
Product customization	0.327	−0.025	*0.684*
Ability to co-design with the customer	*0.644*	−0.074	0.332
Reduction in environmental impact	*0.666*	0.103	0.196
Ability to serve niche markets	*0.604*	−0.187	0.499
Cumulative variance	47.57	59.79	67.24

Notes: KMO = 0.879; Extraction method: principal component analysis. Rotation method: Oblimin with Kaiser Normalization. The values in italics are those considered statistically significant for the Principal Component Analysis. [a]Rotation converged in four iterations

Table VII. PCA on perceived benefits from 3D companies relevant barrier for the development of this technology is the fact that in this industry there is a low knowledge of these new production techniques and a lack of staff training on these themes. Finally the third component, called costs, even though it is the least relevant one (16.32 percent of cumulative variance), refers to the excessive investment perceived by companies in the purchase of such production tools.

Finally, the PCA on the type of use companies have of 3D printings shows two main components (Table IX): the most relevant component (84.00 percent of cumulative variance) is called prototyping and it explains that in majority AM technologies are used in the wood-furniture industry as a tool to create prototypes faster and more freely (Mellor *et al.*, 2014). However, as shown by component two, called product series, there is a segment of companies that is also open to the use of these technologies for the realization of small series of finished products, totally customized in relation to customer needs and also products that are more environmentally friendly (Hague *et al.*, 2004; Berman, 2012; Gershenfeld, 2012; Reeves, 2008). These results are similar to those reached in the automotive industry, where 3D printing has been largely limited to the prototyping of components as a design and engineering validation tool. It has been used to make small parts and sub-assemblies for both visual analysis and quality control. To date, there have been few examples of this technology being used to produce final production parts in vehicles (Richardson and Haylock, 2012).

5. Conclusions

This paper has evaluated the main advantages and disadvantages that AM technologies can bring to companies, considering those that are implementing them in the specific industry of wood-furniture. The research has highlighted how Italian 3D companies in the wood-furniture industry have a specific profile; they are companies aimed at innovating

Table VIII. PCA on perceived limitations from 3D companies

Pattern matrix[a]	Unsuitability	Knowledge and training	Costs
Technology is not suited to the wood-furniture sector	*0.917*	0.143	0.142
Lack of interest in the market	*0.888*	−0.148	−0.014
Lack of knowledge of potential benefits and problems	0.349	*−0.688*	−0.292
Lack of staff training	−0.121	*−0.956*	0.165
Excessively high investment	0.135	−0.075	*0.944*
Cumulative variance	46.73	24.88	16.32

Notes: KMO = 0.567; Extraction method: principal component analysis. Rotation method: Oblimin with Kaiser Normalization. The values in italics are those considered statistically significant for the Principal Component Analysis. [a]Rotation converged in eight iterations

Table IX. PCA on willingness to create with 3D printing

Pattern matrix[a]	Product series	Prototyping
Prototypes	0.000	*1.000*
Small finished product series	*0.855*	0.003
Customized products	*0.913*	0.022
Eco-sustainable products	*0.891*	−0.024
Cumulative variance	59.97	84.00

Notes: KMO = 0.722; Extraction method: principal component analysis. Rotation method: Oblimin with Kaiser Normalization. The values in italics are those considered statistically significant for the Principal Component Analysis. [a]Rotation converged in three iterations through the search for new products and product features, putting design and Made in Italy in the first place. They pay high attention to the image they convey to the market and are highly oriented to the final customer, and to the satisfaction of their needs. Vickery *et al.* (1997) defined four dimensions of manufacturing strength in the furniture industry: innovation, delivery, flexibility, and value, with the latter encompassing the combined effects of quality and cost. The study confirms that Italian businesses have a great tradition in this sector and also a strong ability to innovate, from an environmental and technological point of view. Wood-furniture companies have already begun the transition of their production systems from the paradigms of the linear economy to that one of the sustainable and circular economy, and are increasingly opening up to new production technologies (GreenItaly, 2016).

Reduction in time to market of products and the freedom of design seem to be the two major advantages perceived by companies implementing AM technologies. Due to 3D printing these companies are free to explore their imagination, which bring in a shorter time on the market products with complex shapes and high quality.

Regarding the disadvantages in using 3D printings, these are grouped in three categories, the ones related to the unsuitability of the technology, another linked to the necessity to have more knowledge and training on this issue and one that is economically, which concerns the investment needed to implement 3D printing. However, these are not perceived as actual limitations to the use of AM technologies from those companies that have started to use them.

Considering the way in which companies have started using AM, it can be said that until now 3D printing was mainly used for prototyping (Mellor *et al.*, 2014), but recently it has gained much attention, as the process has proven to be compatible with industrial manufacturing beyond prototyping (Berman, 2012; Gershenfeld, 2012; Reeves, 2008). The research confirms these results; while the majority of respondents say to use it as a useful tool for prototyping, there is a portion of them that is also open to the use of these technologies for the initiation of small series of finished products, oriented to satisfy customer needs. As stated by Chen *et al.* (2015), AM technologies have the possibility of combining the advantages of the other production paradigms and can have a positive impact on sustainable development.

5.1 Implications

Considering practical implications that can derive from this study, first it can be said that AM provides opportunity for organizations to create product innovation, beating competitors on time, as a result of time spent in defining technical specifications of products and in prototyping, which dramatically reduces the time to market of the same. Moreover 3D printing may allow to experiment with their business models. The transition to direct digital manufacturing will lead to digital designs being kept on file; the ability to reproduce these files as spare parts for repair and remanufacturing will enable product life extension and provides incentives for product-service business models. Because DDM eliminates tooling, a product can be manufactured on the same day that the design is completed. This enables companies to produce an instant prototype and react faster to the demands of the user (Singh, 2015). The application in the wood-furniture industry would lead to the direct realization of final end-user products completely customized according to customer needs. For example a chair manufacturer could make chairs of every size and shape at the request of the individual customer, as craftsmen did in the past.

Wood is currently a challenging material for AM, but there are studies such as Henke and Treml's (2013), which show progresses in using wood based bulk materials for creating products with 3D printing. The joint use of these materials and AM technologies would be a game-changer and an important element of innovation for this particular industry.

Moreover AM technologies can create opportunities for more sustainable productions and the development of competitive strategies in their own reference market, owing the creation of a more sustainable value chain that is shorter, smaller, more localized and more collaborative, with also the ability to serve unexplored niche markets.

5.2 Limitations and future research

The first limitation of this research may derive from the fact that a specific industry (i.e. wood furniture) was investigated, therefore a future research line could be to investigate the main advantages and disadvantages of 3D printing in other different and important for Italian sectors such as for example the mechanical, textile or food industry in order to compare differences and similarities.

Another limitation could derive from the fact that the sample is composed only of Italian companies. Nevertheless it was the aim of this paper to directly examine the Italian reality in order to understand how these new technologies are perceived and developed in the Italian context. These limitations give rise to another suggestion for future research; it would be important to expand the analysis of the main benefits and limitations of AM to other countries outside Italy, within Europe such as Germany, Poland and France as they are among the top producing countries in the wood-furniture industry, to see if these results could be confirmed.

Moreover a third limitation may derive from the fact that this research is based on only empirical data, therefore for future research it could be important to supplement the survey findings with a few in-depth qualitative interviews in order to have more information on aspects that were not considered in the survey, for instance the order to delivery strategy of the firms and volume and variety of productions, and also to understand depth of the type of strategy these companies are developing owing to the investment in AM technologies.

Finally further studies could investigate deeply of the advantages and challenges of 3D printing, through deep-dive single case studies and comparative case studies of different sectors, organizations, products and components, along with models of AM-based production systems.

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Appendix. SURVEY: THE USE OF ADDITIVE MANUFACTURING IN THE WOOD-FURNITURE INDUSTRY

1. With reference to the number of employees your business can be classified as:
   - Micro business (<10 employees)
   - Small business (11-49 employees)
   - Medium business (50-249 employees)
   - Large business (More than 250 employees)
2. Your company's turnover is (refer to the financial year 2015):
   - $\leqslant$ 2 millions euros
   - Between 2 and 10 millions euros
   - Between 10 and 50 millions euros
   - > 50 millions euros
3. To which sector of the woo-furniture industry do your company belong?
   - Accessories
   - Bathroom furnishings
   - Furnishings for bars and shops
   - Outdoor furnishings
   - Collectivity
   - Bedroom furnishings
   - Kitchen furnishings
   - Living room furnishings
   - Matresses
   - Upholstered furnishings
   - Classic furnishings
   - Domestic multiproducts
   - Panels
   - School furnishings
   - Semi finished products
   - Office furnishings
   - Other
4. Where is your company located in Italy??
   - Northern regions
   - Center regions
   - South regions and Islands
5. What is your company's reference market?
   - Italy
   - Italy and Europe
   - Italy, Europe and International markets

6. Your company makes products with a price range that is:
    - Low
    - Lower-middle
    - Medium
    - Upper-middle
    - High
7. How much do you pay attention to: (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Creation of customized products
    - Creation of modern and innovative products with high design
    - Creation of quality products that meet the standards of the "Made in Italy"
    - Creation of sustainable products (recyclable and with the least possible waste of resources)
    - The quality of the materials used for the creation of products
    - The enhancement of the brand to be competitive on the market
    - The image of the company communicated to customers
8. Do you realize prototypes in your company?
    - Yes
    - No
    - At other suppliers
9. Does your company own or use a 3D printer?
    - Yes
    - Yes, we do external machining
    - No, but we would like to buy it in the short term
    - No

ANSWER TO THE FOLLOWING SECTION ONLY IF WORKING WITH 3D PRINTER (internally or externally), OTHERWISE GO TO THE NEXT SECTION

10. What percentage of its total production (including prototypes) is made in 3D?
    - < 10%
    - 11-20%
    - 21-35%
    - 36-50%
    - 50-80%
    - > 80%
11. Indicate the benefits you have gained from the introduction of 3D printing: (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Reduction in time to define technical specifications of products
    - Reduction in prototyping time
    - Reduction in production time
    - Reduction in time to market
    - Reduction in costs of materials
    - Reduction of inventory and unsold costs
    - Reduction in transport costs
    - Reduction of labor costs
    - Energy saving
    - Creation of new products with complex geometries, increased performance and quality
    - Creation of a new business model: offer of a virtual model
    - Greater chance of internationalization
    - Shift of production to retail outlets
    - Product customization
    - Ability to co-design with the customer
    - Reduction in environmental impact
    - Ability to serve niche markets

12. Indicate what may be the main limitations to the implementation of 3d printing techniques in the wood-furniture industry (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot):
    - Technology is not suited to the wood-furniture sector
    - Lack of interest in the market
    - Lack of knowledge of potential benefits and problems
    - Lack of staff training
    - Excessively high investment

13. How much are you oriented to the realization with 3D printers of: (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Prototypes
    - Small finished product series
    - Customized products
    - Eco-sustainable products

ANSWER TO THE FOLLOWING SECTION ONLY IF NOT WORKING WITH 3D PRINTERS

14. Why don't your company use 3D printers? (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Technology is not suited to the wood-furniture sector
    - Lack of interest in the market
    - Lack of knowledge of potential benefits and problems
    - Lack of staff training
    - Excessively high investment

15. Indicate how much you think you can achieve the following benefits introduction 3D printing in your production: (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Reduction in time to define technical specifications of products
    - Reduction in prototyping time
    - Reduction in production time
    - Reduction in time to market
    - Reduction in costs of materials
    - Reduction of inventory and unsold costs
    - Reduction in transport costs
    - Reduction of labor costs
    - Energy saving
    - Creation of new products with complex geometries, increased performance and quality
    - Creation of a new business model: offer of a virtual model
    - Greater chance of internationalization
    - Shift of production to retail outlets
    - Product customization
    - Ability to co-design with the customer
    - Reduction in environmental impact
    - Ability to serve niche markets

16. How much would you be oriented to the realization with 3D printers of: (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Prototypes
    - Small finished product series
    - Customized products
    - Eco-sustainable products

CONCLUSIVE SECTION (FOR ALL RESPONDENTS)

17. How do you feel that working environment conditions (safety, ergonomics, noise, dust, temperature) affect worker productivity? (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)

18. How much do you pay attention to the working environment of your workers and employees? (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)

19. Do you think new digital technologies can affect the working environment?
    - Yes, in a positive way
    - Yes, in a negative way
    - I don't know
    - No

20. How much do you think the use of 3D printers can lead to emissions (due to the melting techniques of the materials they use) that will affect the air quality of the working environment? (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)

21. Indicate the degree of adoption of 3D printing by actors in your supply chain (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)
    - Supply chain partners
    - Linked companies
    - Competitors
    - Suppliers
    - Contractors

22. How do you feel it is important to start or continue investing in additive manufacturing and digital technologies so that your company remains competitive on the markets? (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot)

23. How do you feel that 3d printers and other digital technologies can represent the turning point that will allow the advent in the industry of a new industrial revolution? (Likert 1-5: 1= not at all; 2= few; 3= indifferent; 4= enough; 5= a lot).

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