Lana Jarža, Anka Ozana Čavlović, Stjepan Pervan, Nikola Španić, Miljenko Klarić, Silvana Prekrat[1]

Additive Technologies and Their Applications in Furniture Design and Manufacturing

Aditivne tehnologije i njihova primjena u dizajnu i proizvodnji namještaja

REVIEW PAPER
Pregledni rad
Received – prispjelo: 27. 1. 2022.
Accepted – prihvaćeno: 3. 10. 2022.
UDK: 684.4
https://doi.org/10.5552/drvind.2023.0012

ABSTRACT • *This paper deals with an overview of additive manufacturing and its segment - 3D printing, which is today rapidly and widely used (Agashe et al., 2020) for personal and high-capacity production. The paper discusses the possible positive factors such as small and personalized production series, cheaper design and production process, complex geometry, bionic structures (whose surfaces are complicated to make, and are copy of biological organisms) and negative factors such as lack of educated specialists and trainings. Those facts are affecting the implementation of these technologies in different segments of the design, product development and furniture production. The impacts of new technologies on the design and production of rapid prototypes and finished products in furniture industry are analyzed. The positive results of using additive manufacturing indicate that, in spite of minor obstacles and problems with connecting different production processes, additive production will have a significant place in the future of furniture design and production. The most important advantages of 3D printing is fast prototyping, one piece production, free form designing and the use of bio-based materials and their possibility of recycling.*

KEYWORDS: *additive manufacturing; furniture modelling; 3D printing; furniture design; bio – based materials*

SAŽETAK • *U radu se opisuje aditivna tehnologija 3D printanja koja se danas ubrzano i široko primjenjuje (Agashe et al., 2020.) u maloj i industrijskoj proizvodnji. U radu se opisuju mogući pozitivni čimbenici kao što su male i personalizirane proizvodne serije, jeftiniji dizajn i proizvodni proces, složena geometrija, bioničke strukture (površine složene za izradu, a kopije su bioloških organizama), ali i negativni čimbenici poput nedostatka obuke i educiranih stručnjaka. Navedeni čimbenici utječu na implementaciju tih tehnologija u različitim segmentima dizajna, razvoja proizvoda i proizvodnje namještaja. Analizirani su utjecaji novih tehnologija na dizajn i proizvodnju brzih prototipova i gotovih proizvoda u industriji namještaja. Pozitivni rezultati primjene aditivne tehnologije pokazuju da će ona, usprkos manjim preprekama i problemima povezivanja različitih proizvodnih procesa, imati važno mjesto u budućnosti dizajniranja i proizvodnje namještaja. Najvažnije prednosti 3D printanja jesu brza*

[1] Authors are researchers at University of Zagreb, Faculty of Forestry and Wood Technology, Department of Wood Technology, Zagreb, Croatia. https://orcid.org/0000-0003-1205-4877, https://orcid.org/0000-0003-3882-2889, https://orcid.org/0000-0002-0618-4993, https://orcid.org/0000-0002-0484-0125, https://orcid.org/0000-0002-1868-1567, 0000-0003-3147-0841

izrada prototipova, proizvodnja u jednom komadu, dizajn slobodnih formi i upotreba proizvodnih materijala te mogućnost njihova recikliranja.

KLJUČNE RIJEČI: *aditivna proizvodnja; modeliranje namještaja; 3D printanje; dizajn namještaja; prirodni materijali*

1 INTRODUCTION
1. UVOD

Additive manufacturing (AM) is a specialist and complex manufacturing niche. The development of additive manufacturing has huge influence on the production process in the furniture sector. 3D printing offers almost unlimited possibilities for creativity. In terms of technology, it is completely different from the traditional subtractive type of production (Kietzmann *et al*., 2015) and gives it a lot of advantages especially in design. The possible uses of 3D printing are: fast prototype, one piece production, complete product manufacturing, education and testing of ergonomics. Therefore, it affects production from the initial stages – from base model to the final stages of finished products. To be able to use additive manufacturing, it is necessary to think differently. It is necessary to determine the purpose of using available technology and material to be able to achieve full benefits of additive technology. There are doubts about the meaning of the terms AM and 3D printing. Both terms are often used interchangeably, and they are considered synonymous by some authors (Weller *et al.,* 2015). On the contrary, other authors consider AT and 3D printing to be two different terms (Gibson *et al.,* 2010; Mellor *et al*., 2014). As stated by Ford *et al.* (2016) AT is not just one technology but covers a range of technologies. Both, the term additive manufacturing, and the term 3D printing are used when talking about three-dimensional printing of prototypes or real pieces of furniture. Because of almost unlimited application, the manufacturing has entered the era of artificial intelligence, digitalization, and networking (Xu *et al.* 2019). The versatility and more use of AM are confirmed by Berman (2012).

Regardless of whether it is the production of furniture, clothing (Sun and Zhao, 2017), medical implants (Schubert *et al.,* 2013), cars, jewellery, or artificial organs (which use layers of human cells), this technology is in rapid development and is already widely used (Ngoa *et al*., 2018). Recent advances in research and development have already enabled its application for private use in households. Additionally, also design education and courses are adapted to the new compatible technologies that include 3D rapid prototyping (Yulvan, 2020). 3D printing enables consumers around the world to transform digital data into physical products and vice versa, thus facilitating access to innovation (Rindfleisch *et al*., 2017). This allows the user to progress in the process of developing new products, in the way that he/she can use digital tools, such as 3D scanners and 3D printers, to collect and/or generate data, and in the end to create and offer a range of new products on the market. A positive feature is also that 3D printing allows anybody with lower manual skills to produce very demanding and complicated products (as craftsmen once did), which makes such furniture or furniture parts unique.

2 ADDITIVE MANUFACTURING AND OCCURRENCE OF 3D PRINTING
2. ADITIVNA PROIZVODNJA I POJAVA 3D PRINTANJA

2.1 Historical review of additive manufacturing
2.1. Povijesni prikaz aditivne proizvodnje

Production of 3D printers began in the 1980s with the development as an auxiliary simple technology for making rapid prototypes. As well as moulding and welding, printing is also considered as additive manufacturing due to the process of adding material, which creates a new body. Previously applied procedures are based on cutting and removing material. In the period from early 1980s to 1988, various 3D printing processes were designed thanks to the high demand for rapid prototyping. The first ideas and key detailed information for creating the process of stereolithography were given in the 1980s by the Japanese physician Hideo Kodama, who invented the laser approach to curing with one laser beam using photopolymerization.

In the same years, Oliver de Witt together with Jean Cloude Andre worked on research and invention of 3D printers, and in 1986 a patent was granted for the stereolithographic process. The development was not completed due to the uncertainty of the application of this technology. At the same time, Charles Hull successfully patented stereolithography, *i.e.,* solidification or resin printing. It is an ongoing process consisting of curing or solidifying a photosensitive polymer in contact with an ultraviolet laser and an adequate resin (Wong and Hernandez, 2012).

2.2 Preparation of CAD models for 3D prototyping
2.2. Transformacija CAD modela za izradu 3D prototipa

A suitable computer program, equipment and adequate materials are needed for 3D printing (Kralj,

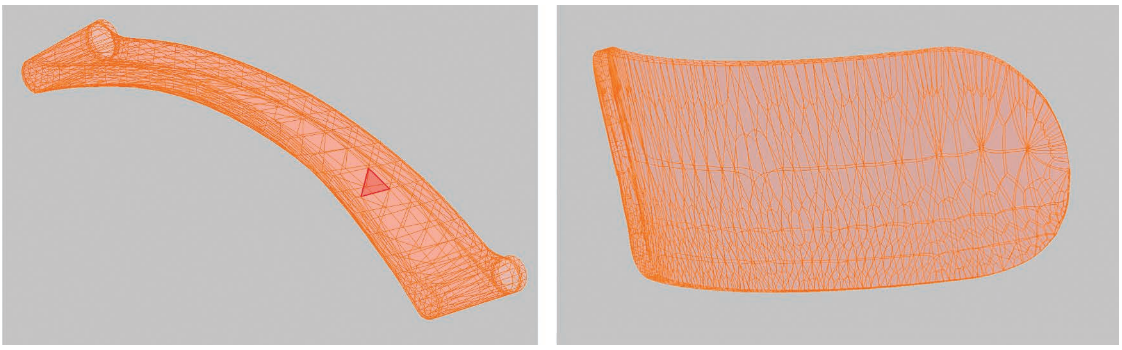


Figure 1 STL file format of chair backrest made of lines and triangles; (Jarža, L.: 3D model photography, 2021)
Slika 1. STL datoteka modela naslona stolice sastavljenoga od linija i trokuta (slika 3D modela: Jarža, L., 2021.)

2017). The first step is to create the wanted model in the program, then the model needs to be converted into a readable device format for 3D printer. The basic 3D model is converted in STL format to get a readable format that consists of lines and surfaces combined into triangles. With terms stereolithography, the abbreviation STL standing for "Standard Triangle Language" and "Standard Tessellation Language" is also used. This is a universal format used to transfer information from modelling programs and can be exported from and to most CAD software packages. The process of creating a STL file is to convert the continuous geometry in a CAD file into triangles or a list of triplet coordinates *x, y* and *z* coordinates and a normal vector into triangles (Wong and Hernandez, 2012). Each triangle, which represents a given area, is characterized by three vertices and the corresponding unit normals (Pascucci *et al*., 2018). The STL format only supports a three-dimensional description of surface geometry without generating print information such as texture or colour (Hiller and Lipson, 2009). Depending on the complexity and size of the model, each vertex is part of three or more triangles and could be read as a 3D body. Szilvśi-Nagy and Matyasi (2003) provide a method for detecting deficiencies in the representation of the surface when using the STL format. Figure 1 shows a 3D body of a chair backrest which is made of the above-mentioned triangles. They are an integral part of a model and important for further usability of the files. If the link is "split", it is not visible to the printer when reading the format. For the print format to be functional, it must be non-specific or adaptable to each printing machine and have the ability to read all elements of the model, including models default colours and materials. Also, because of the rapid advancement of this technology, the format should be "up-to-date" or readable regardless of computer software updates. Groenendyk and Gallant (2012) write about the challenges of preparing files for printing, and Wu and Cheung (2005) about the possibilities for enhancing the printing format.

The advantages of this format (Hiller and Lipson, 2009) include simplicity, portability (format), and low-requirements of working computer memory, while the disadvantages are geometry leaks, incompatibility with colours and materials, poor scalability, and lack of auxiliary information for printing. Based on these disadvantages, they suggest new solutions for use in 3D printing. Their proposal is XML based and AMF format (they give precision, multiple materials and multiple colours at once) but the success of a file format depends on its adoption by users. Nevertheless, today with the development of new materials and hardware, these disadvantages have been reduced, including the lower cost, and better properties of materials, more colours, *etc*.

3 TECHNOLOGY OF 3D PRINTING
3. PRIMJENA TEHNOLOGIJA 3D ISPISA

Additive manufacturing could be divided into two categories: regarding the material required for printing or the type of technology. Thus, the best known are SLS (selective laser sintering); SLM (selective laser melting); EBM (electronic beam melting - which uses the powder materials for printing); SLA (stereolithography - the first invented using photopolymers and UV light); LOM (laminated object manufacturing - not so used because of the amount of needed material and difficult removal of residual material, INKJET, LENS (laser engineered net shaping); FDM (fused deposition modelling) and others described by (Kariž *et al.,* 2017). There are many technologies for a variety of applications, but for the furniture production and product development, FDM is the most frequently used due to the possibility of joining the wood with polymers. This method uses the thermoplastic polymers, since they are compatible with clay, metal, wood, and others. This technology uses heat for energy and has a lot of advantages including cheap printers, simultaneous printing with multiple materials, etc. SLS uses powder, resulting in high accuracy, strength, stiffness, and high density and can also be used in furniture production. Figure 2 shows the examples of FDM and SLS printed models.

a) b) c)

Figure 2 Examples of printed models: a) SLS technology printed models (https://3dprint.com/); b) FDM technology printed model (https://www.printyourmind3d.ca/products/print-your-mind-3d-woodfill-filament?variant=43074437318); c) FDM technology printed model (https://www.forust.com/)

Slika 2. Primjeri isprintanih modela: a) model ispisan SLS tehnologijom (https://3dprint.com/); b) model ispisan FDM tehnologijom (https://www.printyourmind3d.ca/products/print-your-mind-3d-woodfill-filament?variant=43074437318); c) model ispisan FDM tehnologijom (https://www.forust.com/)

4 APPLICABLE MATERIALS IN 3D PRINTING
4. MATERIJALI ZA PRIMJENU U 3D PRINTANJU

Innovation and progress mean innovation in both technology and application of new materials. Additive manufacturing printing materials are available in different forms as powder, filaments, pellets, granules, resins, etc. The choice depends on the application and properties. Various materials are available on the market, such as polymers, metal-based materials, wood based, ceramic, concrete, etc. Some of these polymers are (polylactic acid), (*2012), ABS (acrylonitrile butadiene styrene), PVA (polyactic) PC (polycarbonate), nylon, and polystyrene.

Frequency of use of different materials depends on the requirements of users and the purpose. Polylactic acid or polylactide (PLA) is a widely used plastic filament material, and it is biodegradable and adaptable to all FDM printers. ABS is currently the most flexible material for various purposes available on the market. It is used in the form of filament and is suitable for melting and hardening, also available in all colours. Nylon or polyamide is used in powder form or filament form. Ashraf *et al*. (2018) write about metals and stainless steel in 3D printing. There is also the possibility of printing with powder such as ceramic (Travitzky *et al.,* 2014) or concrete (Nadarajah, 2018). Saad (2016) and Rael (2018) indicate the recommendations for choosing the material depending on the technology used. San Fratello and Rael (2020) describe how to use innovative materials like clay and salt or even soil for 3D printing.

Although synthetic polymers have to be recycled, recycling rates are very low (Garmulewicz *et al*., 2018). There is an interest for using other sustainable and environmentally friendly materials (Sabbatini *et al.,* 2021). Wood residues make a high percentage of waste in wood industry. It can be useful as a material for further use and recycling. It can be used for making wood filaments for 3D printing and not only for ecological reasons (Pringle *et al.,* 2017).

From the designer's or even the customer's point of view, 3D printed product should look like wood and it is less important whether the printed model is real wood. However, for the wood industry, the possibility of recycling wood waste is more important than the mentioned aesthetic impression. Additive manufacturing would be one of the most positive ways of disposing wood waste and wood mass, which mainly ends up in thermal power plants. Numerous studies have shown a positive trend towards lignocellulosic fillers that are increasingly replacing synthetic fibres, emphasizing their mechanical properties, such as low density, good thermal insulation, low cost, and availability (Ayrilmis *et al*., 2019). Cellulose does not cause allergies, and withstands high processing temperatures between 175-250 °C needed for 3D printing. Such printed elements have the possibility of further processing, carving, sanding, painting, etc. With the use of wood waste, the use of filament of organic origin can also further increase the environmental benefits (Das *et al.,* 2021). In addition to being widely available and renewable material, reusing and recycling would give the waste a new purpose and thus gain in value, which is of extreme importance in the context of the world's climate crisis.

Wood filaments are made by mixing wood sawdust, powder, or particles with polymers, after which the material is extruded. Wood particles must be of a certain fineness and texture to enable its mixing into the polymer (Wimmer *et al.,* 2015). Extrusion deposition and polymer binding are layering technologies that use wood materials (Das *et al.,* 2021). An overview of the problems and advantages of using wood in 3D printing is explained by Gardner and Wang (2019).

The research of Wahab *et al.* (2013) confirms the sustainability of wood waste - sawdust for use with 3D printing manufacturing with the fact that the fineness of the powder increases the model surface quality. They also state that increasing the sawdust content reduces the properties of hardness and dimensional accuracy. Several authors explore the possibilities of using wood waste for 3D printing depending on its ratio (%) in the filament (Kariž *et al.,* 2016, 2018b). The research was conducted on residues of beech wood (*Fagus sylvatica*) (Kariž *et al.,* 2017; 2018a; Ayrilmis *et al.,* 2019; Rosenthal *et al.,* 2018); Chinese poplar (*Populus lasiocarpa)* - Chinese aspen (*Populus adenopoda*) (Tao *et al.,* 2019), spruce *(Picea abies)* (Henke and Treml, 2013); European poplar (*Populus),* (Bi *et al.,* 2018b); pine *(Pinus)* (Le Guen *et al.,* 2019), (Wechsler and Hiziroglu, 2007) and olive wood *(Olea europaea)* (Smardzewski *et al.,* 2018).

Kariž *et al.* (2017) investigated the impact of beech particles present in wood content on 3D printing. The wood particles in the filament reduced the density of the printed parts due to the lower density of the wood compared to synthetic polymers. The surface of the printed parts without the addition of wood is smoother and without cavities. The increase of wood particles increased the roughness of the printed element. Nevertheless, their results showed that wood can be used as a component in 3D printing materials and that a small percentage of wood dust strengthens the filament structure by up to 10 %. But also, with increasing percentage of wood dust, tensile strength decreases.

Between the layers, certain stresses may occur due to shrinkage / swelling *e.g.,* stresses during cooling of molten polymers and bending of the product (Kariž *et al.,* 2017). The influence of moisture content from wood powder and air on 3D printed wood was described by Kariž *et al.* (2018b) and Ayrilmis *et al.* (2019). Grujović *et al.* (2016) prove that 3D printed furniture connecting elements are useful for wide application. That would reduce the cost of making small series of complex furniture elements. Research on the production of extruded wood concrete, whose composition is limestone, cement, and untreated coniferous wood chips, has also shown positive results (Henke *et al.,* 2016).

Considering that the 3D printing is a relatively new technology, the production of adequate wood filament requires a lot of research focusing on issues such as types of wood used, particle size, type of natural polymers, *etc*. Table 1 presents the advantages and disadvantages of wood in the application of additive manufacturing and 3D printing based on previous research (Wimmer *et al.,* 2015; Henke, *et al*., 2016; Bi *et al*. 2018a; Das *et al*., 2021; Wahab *et al.,* 2013; Ayrilmis *et al*., 2019; Rosenthal *et al*., 2017; Kariž *et al.,* 2017).

5 IMPLEMENTATION OF AM IN FURNITURE PRODUCTION
5. IMPLEMENTACIJA ADITIVNE PROIZVODNJE U PROIZVODNJI NAMJEŠTAJA

The choice of adoption of new technologies in a company depends on the needs and priorities of the production department. There are good reasons for and against the introduction of 3D printing. Aydin (2015), based on a real projects overview, emphasizes innovation as key in the development of this industry. For small-and medium-sized companies' benefits, challenges and business factors have significant influence on the adoption of the additive manufacturing (Kulkarni *et al.,* 2020). According to the production department, technology and costs are the most important implementation factors, while the marketing and development department consider future market placement as the priority, followed by the impact on the environment (Yeh and Chen, 2018). Pascucci *et al.* (2018)

Table 1 Advantages and disadvantages of wood used in 3D printing
Tablica 1. Prednosti i nedostatci upotrebe drva u 3D printanju

Wood filaments in 3D printing / *Filamenti na bazi drva u 3D printanju*	
Advantages / *Prednosti*	**Disadvantages** / *Nedostatci*
Ecological aspects, recyclability, and biodegradability *ekološki aspekti, neštetnost za okoliš, mogućnost recikliranja i biorazgradivost*	Technical difficulties when printing - filling and blocking nozzles with wood powder *punjenje i blokiranje sapnica drvnim prahom*
Reducing the cost of purchasing materials possibility of making it inside the factory *smanjenje troškova nabave materijala za ispis, mogućnost izrade unutar tvornice*	Higher percentage of wood reduce mechanical properties, and surface quality *veći postotak drva smanjuje mehanička svojstva predmeta i kvalitetu površine*
Sustainability of use of 3D printing manufacturing *održivost proizvodnje 3D printanja*	Low wood compatibility with printing – materials *niska kompatibilnost drva s ostalim materijalima*
Easy workability, sanding, colouring of the printed element *laka obradivost ispisanog elementa*	Rougher surface *hrapavija površina*
Aesthetic characteristics (appearance of real wood) *estetska obilježja (izgled pravog drva)*	

determined the key factors common to all productions in terms of implementation of additive manufacturing in production processes. These are: the purpose of use, company size, time of use, type of material and transition from conventional production techniques. Additive manufacturing must be interconnected with market and production needs. The plan for the implementation of additive manufacturing in the actual production is described by Mellor *et al.* (2014), and as the main characteristics for the introduction of technology they state: the degree of adaptability, increased functionality through design and the possibility of producing small quantities. The reasons against are the high price of large-scale printing machines despite the use of cheap recycled material and the slowness of the technology, e.g. 24 hours for one backrest.

The mentioned value can be associated with the increase of competitiveness. The product can be quickly improved with new properties or design details. Every aesthetic supplement that makes the product recognizable and more interesting increases the interest of customers and the product gains in value. Most often, these are examples of furniture parts that are not available on the market, and due to their design, they must be special and different. The possible uses in production that could be important for the implementation are: full size prototyping and printing furniture in large scales; printing elements of furniture; replacement of furniture pieces; ergonomy testing; printing furniture joints, reverse engineering and rapid prototyping. These few examples are shown in Figure 3. The example for the replacement parts is presented by 3D printed elements shown in Figure 3d. It describes the furniture part whose solution did not exist on the market and a new one was created. Innovative elements are very suitable for 3D printing (Podskarbi *et al*., 2016; Krzyżaniak *et al.,* 2020). Those made with 3D printing may enrich the product not only with an aesthetic value but also with a new function. They are printable with different materials, interchangeable, available in all places where there is the possibility of 3D printing, even in households. This reduces the cost of ordering and delivery time and allows the possibility of personalization. Users who want to be unique are the most common target group to be recipients of such furniture. Interesting examples of 3D printed elements incorporated into the design of furniture are shown in the works of Pandolfo (2016) and Jarža (2016).

Aiman *et al.* (2020) compare furniture joints made of existing material and traditional production type and Fused Deposition Modelling (FDM) fabrication method. Results showed that the elements made

Figure 3 Uses of 3D printing in production: a) 3D printed large scale chair (https://parametrichouse.com/3d-printed-furniture/); b) Part of furniture (https://ultimaker.com/learn/3d-printing-in-furniture-design); c) Joints development (Prekrat, S., photography); d) Parts for testing of ergonomy (https://3dprinting.com/3d-printing-use-cases/how-the-furniture-industry-benefits-from-3d-printing/); e) Replacement of parts (Jarža, L., photo of rendered 3D model)

Slika 3. Primjena 3D ispisa u proizvodnji: a) 3D printana stolica stvarne veličine (https://parametrichouse.com/3d-printed-furniture/); b) dijelovi namještaja (https://ultimaker.com/learn/3d-printing-in-furniture-design); c) razvoj elemenata za sastavljanje namještaja (fotografija: Prekrat, S.); d) elementi za ergonomsko testiranje (https://3dprinting.com/3d-printing-use-cases/how-the-furniture-industry-benefits-from-3d-printing/); e) zamjenski dijelovi (fotografija izvedenog 3D modela: Jarža, L.)

Figure 4 3D printed element created by reverse engineering (https://3dprint.com/45399/marie-antoinette-museum-chair/)
Slika 4. 3D printani elementi kreirani povratnim inženjeringom (https://3dprint.com/45399/marie-antoinette-museum-chair/)

from waste materials printed by FDM method are fully functional and of suitable quality. This way of reusing and recycling the residue from production (which is thrown away in large quantities) could be used in production of filaments for 3D printers.

In traditional (convectional) production some products and elements have become a thing of the past, they are no longer produced, technologies are outdated or not in line with the new trends. 3D print is part of reversible engineering. The example of the application of this technology is the restoration of furniture elements (Figure 4). It includes three-dimensional scanning of elements, digitization of models and creation of documentation for CAD programs that support the format for 3D printing (Celent *et al.,* 2016). The advantage of using this manufacturing, which includes printing of specific parts, also allows the production of a single piece, which does not affect the economic aspects of the remaining production.

Virtual furniture design is another activity developed from the additive manufacturing and it includes 3D modelling of furniture for architecture and interior design. This allows useful interactive participation of the customers in the selection process when buying furniture (Lin and Hsu, 2004; Chua *et al*., 1999).

Due to the commercialization of the 3D printers, many smaller manufacturers decide to implement it in accordance with their financial and spatial possibilities. Advances in information science enable them to use services in the data cloud, which solves several limitations, including the problem of lack of professional staff and the implementation of personalized individual production (Xu *et al*., 2019; Krsnik, 2019). This is good because 3D printing is a way of production that occasionally needs prototyping or parts manufacturing services. That would enable them to avoid the cost of implementing new technology and training of workers. Services in the cloud connect three types of users: manufactures, designers, and consumers. The advantages of this possibility include reduced disruption to the daily flow of production. Rayna *et al*. (2015) explain the market developments for design, 3D printing, service, and group collaboration with users on digital platforms.

6 ADVANTAGES AND DISADVANTAGES OF ADDITIVE MANUFACTURING
6. PREDNOSTI I NEDOSTATCI ADITIVNE PROIZVODNJE

The need of fast prototypes, new design elements and innovative furniture is growing rapidly, and competition is becoming fierce. Shehata* wrote about the advantages of 3D printing. In recent years, design has become a widespread activity that launches many new solutions around the world daily. In order to be competitive, it is necessary to react quickly to launch a new product on the market and to be faster than the competition. This includes prototyping, testing, finishing and market presentation. This is where this 3printing comes forward. Top *et al.* (2019) point out that 3D printing of parts, assemblies, and segments helps to achieve this goal. This method allows the creation of very complex shapes with high precision and maximum material savings, and an additional plus is that 3D models and print data once prepared can be easily and quickly modified when needed. Ngoa (2018) describes the flexibility of this technology, Tofail *et al*. (2018) its benefits and Grujović *et al.* (2016b) write about its cost-effectiveness.

Designing new solutions and products using fast prototypes is now much simpler. In short time, it is possible to change dimensions, materials, etc. on the basic 3D model, depending on the requirements, and print a new sample, if necessary. With rapid prototyping, it is much easier to control the ergonomics, dimensions, product stability, usability and other characteristics that are difficult to assess on-screen. According to Pascucci *et al.* (2018), this manufacturing gives freedom of design expression, reduces the need for special tools and the cost of production of individual specific parts and components of complex geometric shapes. Murmura and Bravi (2018) quote advantages for creative manufacturing industries and those that develop furniture. This includes reducing the time of product launch on the market, main limitations of the inadequacy of manufacturing and the need for more educated employees, increasing at the same time the freedom of design expression. Opposite of that, Schniederjans (2017) and Ford *et al.* (2016) claim that, despite all the advantages of this technology, it has not yet reached high levels of adoption mainly because of regulatory and legal issues, high initial investment costs, increased electricity consumption compared to traditional methods and needs for new skills and competencies.

Holzmann *et al.* (2017) outline the positive aspects of 3D printing as opportunity from the perspective of small producers. Opposite of this, Bogers *et al.* 2016 conclude that 3D print can have a devastating impact on business models because of the changes in the production processes that negatively affect the processes of supply and transport, which will no longer be needed because of possibilities of self-printing (Öberg, 2018). Jumaah (2018) also writes about the consequences of localizing AM on supply, transport and transportation activities and states the positive effects on the environment and savings in financing urban infrastructures. Holzmann *et al.* (2020) explore new business models and explain how companies currently underutilize the key benefits of 3D manufacturing.

Ryan *et al*. (2017), Oettmeier and Hofmann (2016), Rogers *et al.* (2016), Durach *et al.* (2017) are convinced that, by the implementation of additive manufacturing, the systems of transport and supply activities will be excluded from the whole process precisely because then manufacturers will be oriented to reduce unnecessary costs by introducing new machines that could improve production and products and make something they ordered. Improving production and products, in that case, would mean added value to the factory and a better product for the market.

Reducing costs and time, reducing environmental pollution, and even reducing injuries at work are listed by Sakin and Kiroglu Caner (2017) as the main advantages of the implementation of this technology in construction companies. This is applicable to the wood industry as well because the machines can do jobs instead of workers. Implementation of this technology in furniture production processes would contribute to significant savings in some areas, including the usage of only the amount of material that is needed for their design. This means to use less resources and thus reduce waste, to create more innovative designs because 3D

Table 2 Advantages and disadvantages of implementations of additive manufacturing
Tablica 2. Prednosti i nedostatci implementacije aditivne proizvodnje

Implementation of additive manufacturing / *Implementacija aditivne proizvodnje*	
Advantages / *Prednosti*	**Disadvantages** / *Nedostatci*
Early error detection during design process *prepoznavanje i uklanjanje pogrešaka u procesu oblikovanja*	Lower product strength, delamination may occur during loading / *manja čvrstoća proizvoda, mogućnost pojave raslojavanja*
Check of product assemblies / *provjera sastavljanja sklopova proizvoda*	Possible lower mechanical properties of prototypes depending on filament quality and technology / *moguća lošija mehanička svojstva prototipova, ovisno o kvaliteti filamenta i o tehnologiji*
Making individual or unique products *izrada pojedinačnih proizvoda ili unikata*	Vanishing of existing traditional mass production plants *zatvaranje postojećih tradicionalnih proizvodnih pogona za serijsku proizvodnju*
Making of 3D models and visualizations *izrada 3D modela i vizualizacije*	Lack of professional staff and educated training *nedostatak stručnog osoblja i adekvatne obuke*
Digital storage of the model, quick modification and adaptation to a new product / *digitalna pohrana modela i brza izmjena i prilagodba novom proizvodu*	Sustainability of production processes / *održivost proizvodnih procesa*
The user / customer personally participates in the process of creation / *osobno sudjelovanje korisnika/kupca u procesu kreiranja*	Lower 3D printer speed compared to conventional productions / *sporost 3D pisača u usporedbi s konvencionalnim proizvodnjama*
Rapid prototyping *brza izrada prototipa*	Lack of knowledge of 3D technology industrial printing and application / *nedovoljno poznavanje industrije 3D tehnologije ispisa i primjene*
Quick production of devices or parts shortens delivery time *brza izrada priručnih alata ili dijelova, što skraćuje vrijeme isporuke*	Limited number of materials and their availability *ograničen broj materijala i njihova otežana dobavljivost*
Reduced production costs (instead of ordering from other factory) and thus reduce cost of transport, storage and subcontracting services / *smanjeni troškovi proizvodnje (umjesto naručivanja), čime se smanjuje i trošak prijevoza, skladištenja te kooperantskih usluga*	More expensive than conventional construction due to high cost of 3D printers / *proizvodnja skuplja od konvencionalne gradnje zbog visokih troškova 3D pisača*
Use of direct production - reducing the number of operations *primjena izravne proizvodnje – smanjenje broja operacija*	3D printers can be too big or they are difficult and expensive to install in place / *3D pisači mogu biti veliki i stoga ih je teško i skupo instalirati na određeno mjesto*
The possibility of making products or parts in the "house" privately or in own factory / *mogućnost izrade proizvoda ili dijelova „u kući", privatno ili u vlastitoj tvornici*	
24/7 technology management / *upravljanje tehnologijom 24/7*	

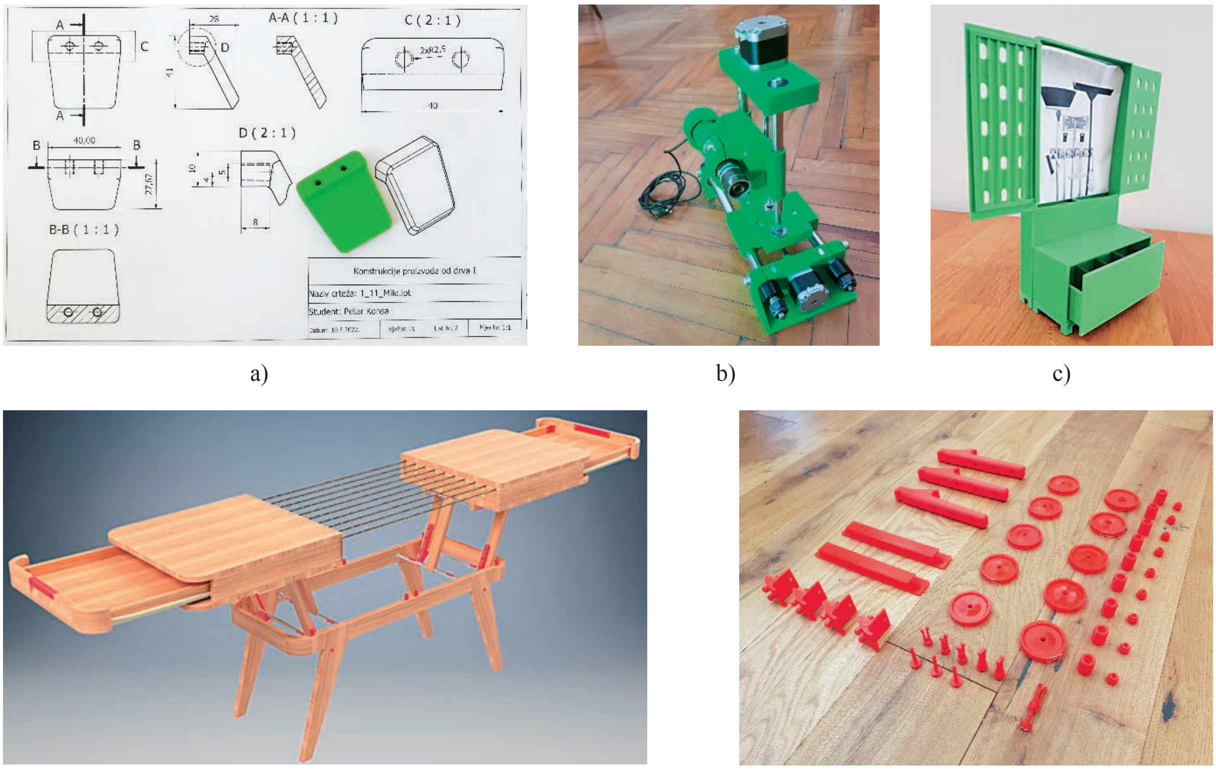
printing can achieve shapes that conventional technologies cannot achieve with lower labour and transport costs and thus enable on-site application. The negatives could be the lack of technical staff, professional staff and workers on printing machines (because some machines require an extra worker). The offer of 3D manufacturing on the market cannot yet replace traditional production of higher capacity but has an impact because the traditional as well as AM face depreciation of machine and labour cost (Steenhuis and Pretorius, 2016; Attaran, 2017). Achillas *et al*. (2017) consider it as an excellent complement to small and micro productions that achieve competitiveness through their application. Table 2 lists the mentioned advantages and disadvantages of additive manufacturing.

Table 2 presents advantages and disadvantages of wide use of additive manufacturing in different production sectors. It should be emphasized that the disadvantages show daily a decreasing trend. Lots of them have already been improved and some problems will be corrected in favour of AM in the near future. The mentioned disadvantages and possibilities can be divided into several groups. They involve the development of the materials, development of printers, reducing costs (of hardware, printers, software, materials, work, or defined properties of the future product) and better education of employees.

Development of printers will reduce printing costs and secure better and cheaper hardware on the market. Development of materials includes improved properties of the printed model and the materials themselves, possibilities of using more colours and their combinations, more available materials, and filaments, even combinations of different materials. Education means more education from primary to higher education, also the implementation of education in regular schooling or additional lifelong learning courses, the so-called lifelong learning. Those properties will enable the wide use, which is the goal of this technology.

7 CROATIAN FURNITURE MANUFACTURER NEEDS
7. POTREBE PROIZVOĐAČA NAMJEŠTAJA NA HRVATSKOM TRŽIŠTU

In Croatia, the wood industry and furniture production do not keep up with new technologies. It can be said that at this time the implementation of additive manufacturing is still slowly progressing, but there are possibilities for the development. 3D technology implementation in solid wood furniture factories depends on the primary interest of the factories, their placement on world markets and their technological capabilities.



a) b) c)

d)

Figure 5 a) Engineering education (Prekrat, S., photography, 2022); b) Devices for research projects (Prekrat, S. photography, 2022); c) Product presentation (Prekrat, S., photography, 2022); d) Creating innovations (Prekrat, S., photography, 2022)
Slika 5. a) Inženjersko obrazovanje (fotografija: Prekrat, S., 2022.), b) uređaji za istraživačke projekte (fotografija: Prekrat, S., 2022.); c) prezentacija proizvoda (fotografija: Prekrat, S., 2022.); d) stvaranje inovacija (fotografija: Prekrat, S., 2022.)

The need for rapid prototyping and new design solutions stems from the wishes to conquer the market with novelties. Only a few such factories show good examples and results, and the examples are shown in Figure 4. The other barriers include the procurement of new technologies and software that would be compatible with the existing machines. For some factories, this means a complete reconstruction and renewal of production and the design of new production processes.

For a greater degree of use of 3D printing in the design and manufacture of furniture, the problem is insufficient knowledge of 3D modelling as a basis for 3D printing. Still, there is progress. As part of the study program at the Faculty of Forestry and Wood Technology, University of Zagreb, students make models of furniture or its parts. Within this program, students use 3D print in product development and innovation, and they manufacture parts for devices in research projects (Figure 5).

Thus, the 3D printing is for now used just for prototyping and product development and not for big series and large furniture (Figure 6). While turning to ecological materials, wooden furniture is a trend on the domestic market, and ecological awareness when buying wooden furniture is still moving in small steps. At present, the companies that are already aiming at the foreign markets could benefit most from this technology.

Rapid prototyping also includes technological process with simple manufacturing (example is small printers and machines for fast prototyping) that most producers could afford and that would greatly support the development process of production or marketing. Positive factors of faster work process, reducing the cost of raw materials spent on the production of test prototype elements, and use of technology only (non-interference of regular production process, where workers would continue to work on their usual positions in production) would certainly show results.

8 CONCLUSIONS
8. ZAKLJUČAK

Today, additive manufacturing could speed up production (in case of rapid prototyping, one piece of unique furniture, alternate pieces of machines, etc.), reduce the cost of the design process and increase product quality. The number of disadvantages is much smaller than advantages. With such manufacturing, it is possible to make small production series, cheaper products, complex geometry, and bionic structures. It allows design freedom of making any shapes or furniture parts and make personalized products for a variety of customers. Additive manufacturing allows optimization of product performances. 3D printing has increased implementation in different fields of furniture production starting with making fast prototypes to final functional products or furniture parts. Figure 7 shows good examples of the mentioned advantages. Also, accelerated development of applied materials, improvement of technologies and reduction of hardware cost in additive manufacturing results in greater application in the design process and furniture manufacturing. Using natural polymers allows green production and possibility of recycling. All this gives the product new added value and lots of possibilities in product development.

Acknowledgements – Zahvala

The article was published as part of the project "Development of innovative products from modified Slavonian oak" by Spin Valis d.d. and partner Faculty of Forestry and Wood Technology, University of Zagreb. The total value of the project is HRK

Figure 6 Example of backrest product development (rapid prototyping) in Croatian furniture manufacturing; (Jarža, L., photography, 2022)
Slika 6. Razvoj proizvoda (brzog prototipa) na primjeru elementa naslona u proizvodnji namještaja (fotografija: Jarža, L., 2022.)

Figure 7 Good examples of 3D printing in furniture manufacturing (https://www.3dnatives.com/en/3d-printed-furniture-130220194/)
Slika 7. Dobri primjeri 3D ispisa u proizvodnji namještaja (https://www.3dnatives.com/en/3d-printed-furniture-130220194/)

55,064,343.84, while the amount co-financed by the EU is HRK 23,941,527.32. The project was co-financed by the European Union from the Operational Program Competitiveness and Cohesion 2014-2020, European Fund for Regional Development.

9 REFERENCES
9. LITERATURA

1. Achillas, C.; Tzetzis, D.; Raimondo, M. O., 2017: Alternative production strategies based on the comparison of additive and traditional manufacturing technologies. International Journal of Production Research, 55 (12): 3497-3509. https://doi.org/10.1080/00207543.2017.1282645
2. Agashe, K. D.; Sachdeva, A.; Chavan, S. S., 2020: 3D printing and advance material technology. International Journal of Grid and Distributed Computing, 13 (2): 1899-1936.
3. Aiman, A. F.; Sanusi, H.; Haidiezu, A. H. M.; Cheong, H. Y., 2020: Design and structural analysis of 3D-printed modular furniture joints. IOP Conference Series Materials Science and Engineering, 932 (1). https://doi.org/10.1088/1757-899X/932/1/012101
4. Ashraf, M.; Gibson, I.; Rashed, G., 2018: Challenges and prospects of 3D printing in structural engineering, 13th International Conference on Steel, Space and Composite StructuresAt, Perth, Australia.
5. Attaran, M., 2017: The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons, 60 (5): 677-688. https://doi.org/10.1016/j.bushor.2017.05.011
6. Aydin, M., 2015: Use of 3D Printing in Furniture Production. In: Proceedings of 3rd Int. Symposium on Innovative Technologies in Engineering and Science.
7. Ayrilmis, N.; Kariž, M.; Kitek Kuzman, M., 2019: Effect of wood flour content on surface properties of 3D printed materials produced from wood flour/PLA filament. International Journal of Polymer Analysis and Characterization, 24 (7): 659-666. https://doi.org/10.1080/1023666X.2019.1651547
8. Berman, B., 2012: 3-D printing: The new industrial revolution. Business Horizons, 55 (2):155-162. https://doi.org/10.1080/1023666X.2019.165154710.1016/j.bushor.2011.11.003
9. Bi, H.; Ren, Z.; Guo, R.; Xu, M.; Song, Y., 2018a: Fabrication of flexible wood flour/thermoplastic polyurethane elastomer composites using fused deposition moulding. Industrial Crops and Products, 122: 76-84. https://doi.org/10.1080/1023666X.2019.165154710.1016/j.indcrop.2018.05.059
10. Bi, H.; Xu, M.; Ye, G.; Guo, R.; Cai, L.; Ren, Z., 2018b: Mechanical, thermal, and shape memory properties of three-dimensional printing biomass composites. Polymers, 10 (11): 1234. https://doi.org/10.1080/1023666X.2019.165154710.3390/polym10111234
11. Bogers, M.; Hadar, R.; Bilberg, A., 2016: Additive manufacturing for consumer-centric business models: implica-

tions for supply chains in consumer goods manufacturing. Technological Forecasting and Social Change, 102: 225-239. https://doi.org/10.1016/j.techfore.2015.07.024

12. Celent, L.; Bajić, D.; Jozić, S., 2016: Reverse engineering process application in single item production. In: Proceedings of international conference Mechanical Technologies and Structural Materials, Split.
13. Chua, C. K.; The, S. H., Gay, R. K. L., 1999: Rapid prototyping versus virtual prototyping in product design and manufacturing. School of Mechanical & Production Engineering; and 2Gintic Institute of Manufacturing Technology. Nanyang Technological University, Singapore.
14. Das, A. K.; Agar, D. A.; Rudolfsson, M.; Larsson, S. H., 2021: A review on wood powders in 3D printing: processes, properties, and potential applications. Journal of Materials Research and Technology, 15: 241-255. https://doi.org/10.1016/j.jmrt.2021.07.110
15. Durach, C. F.; Kurpjuweit, S.; Wagner, M. S., 2017: The impact of additive manufacturing on supply chains. International Journal of Physical Distribution & Logistics Management, 47(10): 954-971. https://doi.org/10.1108/IJPDLM-11-2016-0332
16. Ford, S.; Mortara, L.; Minshall, T., 2016: The Emergence of additive manufacturing: introduction to the special issue. Technological Forecasting & Social Change, 102: 156-159. https://doi.org/10.1016/j.techfore.2015.09.023
17. Gardner, J., D.; Wang, L., 2019: Additive manufacturing of wood-based materials for composite applications. In: Proceedings of SPE Automotive Composites Conference & Exhibition.
18. Garmulewicz, A.; Holweg, M.; Veldhuis, H.; Yang, A., 2018: Disruptive technology as an enabler of the circular economy: What potential does 3D printing hold? California Management Review, 60 (3): 112-132. https://doi.org/10.1177/0008125617752695
19. Gibson, I.; Rosen, W. D.; Stucker, B., 2010: Additive manufacturing technologies, rapid prototyping to direct digital manufacturing, Springer. https://doi.org/10.1007/978-1-4419-1120-9
20. Groenendyk, M.; Gallant, R., 2012: 3D printing and scanning at the Dalhousie University Libraries: a pilot project. https://doi.org/10.1108/07378831311303912
21. Grujović, N.; Zivic, F.; Zivkovic, M.; Sljivić, M.; Radovanovic, A.; Bukvic L.; Mladenovic, M.; Sindjelic, A., 2016a: Custom design of furniture elements by fused filament fabrication. Journal of Mechanical Engineering Science, 231 (1): 88-95. https://doi.org/10.1177/0954406216646401
22. Grujović, N.; Pavlović, A.; Šljivić, M.; Živić, F., 2016b: Cost optimization of additive manufacturing in wood industry. Faculty of Mechanical Engineering, Belgrade. https://doi.org/10.5937/fmet1604386G
23. Henke, K.; Talke, D.; Winter, S.; 2016: Additive manufacturing of building elements by extrusion of wood concrete. In: Proceedings of World Conference on Timber Engineering.
24. Henke, K.; Treml, S., 2013: Wood based bulk material in 3D printing processes for applications in construction. European Journal of Wood and Wood Products, 71: 139-141. https://doi.org/10.1007/s00107-012-0658-z
25. Hiller, J. D.; Lipson, H., 2009: STL 2.0: A Proposal for a universal multi-material additive manufacturing file format, Mechanical and Aerospace Engineering Cornell University, Ithaca NY 14853, USA.
26. Holzmann, P.; Breitenecker, R. J.; Soomro, A. A.; Schwarz, E. J., 2017: User entrepreneur business models in 3DPrinting. Journal of Manufacturing Technology Management, 28 (1): 75-94. https://doi.org/10.1108/JMTM-12-2015-0115
27. Holzmann, P.; Breiteneckerb, R. J.; Schwarza, E. J.; Gregoria, P., 2020: Business model design for novel technologies in nascent industries: An investigation of 3D printing service providers. Technological Forecasting and Social Change, 159: 120193. https://doi.org/10.1016/j.techfore.2020.120193
28. Jarža, L,. 2016: Razvoj drvene radne stolice. Diplomski rad, Sveučilište u Zagrebu, Šumarski fakultet.
29. Jumaah, O., 2018: A study on 3D printing and its effects on the future of transportation, PhD Thesis. Department of Mechanical and Aerospace Engineering.
30. Kariž, M.; Sernek, M.; Kitek Kuzman, M., 2016: Use of wood powder and adhesive as a mixture for 3D printing. European Journal of Wood and Wood Products, 74: 123-126. https://doi.org/10.1007/s00107-015-0987-9
31. Kariž, M.; Šernek, M.; Kitek Kuzman, M., 2017: Possible uses of wood in additive technologies (3D printing). Les/Wood, 66 (2): 71-84. https://doi.org/10.26614/les-wood.2017.v66n02a07
32. Kariž, M.; Sernek, M.; Kitek Kuzman, M., 2018a: Effect of humidity on 3D-printed specimens from wood-pla filaments. Wood Research, 63 (5): 917-922.
33. Kariž, M.; Sernek, M.; Obućina, M.; Kuzman Kitek, M., 2018b: Effect of wood content in FDM filament on properties of 3D printed parts. Materials Today Communications, 14: 135-140. https://doi.org/10.1016/j.mtcomm.2017.12.016
34. Kietzmann, J.; Pitt, L.; Berthon, P., 2015: Disruptions, decisions, and destinations: Enter the age of 3-D printing and additive manufacturing. Business Horizons, 58 (2): 209-221. https://doi.org/10.1016/j.bushor.2014.11.005
35. Kralj, A., 2017: 3D ispis i praktična primjena. Master's Thesis, University North, Department of Multimedia, Design and application, Varaždin.
36. Krsnik, M., 2019: Digitalizacija proizvodnje i proizvodnih procesa. Master's Thesis, Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje.
37. Krzyżaniak, L.; Smardzewski, J.; Prekrat, S., 2020: Numerical modelling of stiffness of rta furniture with new externally invisible and dismountable joints. Drvna industrija, 71 (2): 209-2014. https://doi.org/10.5552/drvind.2020.1953
38. Kulkarni, P.; Kumar, A.; Chate, G.; Dandannavar, P., 2020: Elements of additive manufacturing technology adoption in small- and medium-sized sized companies. Innovation & Management Review, 18 (4): 400-416.
39. Le Guen, M.-J.; Hill, S.; Smith, D.; Theobald, B.; Gaugler, E.; Barakat, A.; Mayer-Laigle, C., 2019: Influence of rice husk and wood biomass properties on the manufacture of filaments for fused deposition modelling. Frontiers in Chemistry, 7:735. https://doi.org/10.3389/fchem.2019.00735
40. Lin, C. H.; Hsu, Y. L., 2004: The influence of a digital architecture on virtual furniture design, CAADRIA. In: Proceedings of the 9th International Conference on Computer Aided Architectural Design Research in Asia, Seoul Korea, pp. 493-504.
41. Mellor, S.; Hao, L.; Zhang D., 2014: Additive manufacturing: A framework for implementation. International Journal of Production Economics, 149: 194-201. https://doi.org/10.1016/j.ijpe.2013.07.008
42. Murmura, F.; Bravi, L., 2018: Additive manufacturing in the wood-furniture sector: sustainability of the technolo-

gy, benefits and limitations of adoption. Journal of Manufacturing Technology Management, 29 (2): 350-371.
43. Nadarajah, N., 2018: Development of concrete 3D printing. Master Thesis, Aalto University School of Engineering.
44. Ngoa, T. D.; Kashania, A.; Imbalzanoa, G.; Nguyena, K. T. Q.; Hui, D., 2018: Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Composites Part B: Engineering, 143 (15): 172-196. https://doi.org/10.1016/j.compositesb.2018.02.012
45. Öberg, C., 2018: Additive manufacturing – digitally changing the global business landscape. European Journal of Management and Business Economics, 28(2): 174-188. https://doi.org/10.1108/EJMBE-11-2018-0116
46. Oettmeier, K.; Hofmann, E., 2016: Impact of additive manufacturing technology adoption on supply chain management processes and components. Journal of Manufacturing Technology Management, 27 (7): 944-968. https://doi.org/10.1108/JMTM-12-2015-0113
47. Pandolfo, B., 2016: From prototype to production: using plastic 3D printed parts in furniture. In: Proceedings of International design conference – design, Dubrovnik, Croatia.
48. Pascucci, F.; Perna, A.; Runfola, A.; Gregori, G. L., 2018: 3 The hidden side of 3D printing in management. Symphonya Emerging Issues in Management, 2: 91-107. https://doi.org/10.4468/2018.2.08pascucci.perna.runfola.gregori
49. Podskarbi, M.; Smardzewski, J.; Moliński, K.; Molińska-Glura, M., 2016: Design methodology of new furniture joints. Drvna industrija, 67 (4): 371-380. https://doi.org/10.5552/drind.2016.1622
50. Pringle, A. M.; Rudnicki, M.; Pearce, J. M., 2017: Wood furniture waste-based 3-D printing filament. Forest Products Journal, 68 (1): 86-95. https://doi.org/10.13073/FPJ-D-17-00042
51. Rael, R.; Virginia San Fratello, V., 2018: Printing architecture: Innovative recipes for 3D printing. Chronicle Books.
52. Rayna, T.; Striukova, L.; Darlington, J., 2015: Co-Creation and user innovation: The role of online 3D printing platforms. Journal of Engineering and Technology Management, 37: 90-102. https://doi.org/10.1016/j.jengtecman.2015.07.002
53. Rindfleisch, A.; O'Hern, M.; Sachdev, V., 2017: The digital revolution, 3D printing, and innovation as data. Journal of Product Innovation Management, 34 (5): 681-690. https://doi.org/10.1111/jpim.12402
54. Rogers, H.; Baricz, N.; Pawar, K. S., 2016: 3D printing services: classification, supply chain implications and research agenda. International Journal of Physical Distribution & Logistics Management, 46(10): 886-907.
55. Rosenthal, M.; Henneberger, C.; Gutkes, A., 2017: Liquid Deposition modelling: a promising approach for 3D printing of wood. European Journal of Wood and Wood Products, 76: 797-799. https://doi.org/10.1007/s00107-017-1274-8
56. Ryan, M. J.; Eyers, D. R.; Potter, A. T.; Purvis, L.; Gosling, J., 2017: 3D Printing the Future: Scenarios for Supply Chains Reviewed. International Journal of Physical Distribution & Logistics Management, 47 (10): 992-1014.
57. Saad, R. M., 2016. The revolution of Materials used in 3D Printing applications in Furniture& Interior Design. International Design Journal, 6 (3): 143-163. https://doi.org/10.21608/idj.2016.90852
58. Sabbatini, B.; Cambriani, A.; Cespi, M.; Palmieri, G. F.; Perinelli, D. R.; Bonacucina, G., 2021: An Overview of Natural Polymers as Reinforcing Agents for 3D Printing. ChemEngineering, 5 (4): 78. https://doi.org/10.3390/chemengineering5040078
59. Sakin, M.; Kiroglu Caner, Y., 2017: Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM. Energy Procedia, 134: 702-711. https://doi.org/10.1016/j.egypro.2017.09.562
60. San Fratello, V.; Rael, R., 2020: Innovative materials for large scale additive manufacturing: salt, soil, cement and chardonnay. Cement and Concrete Research, 134: 106097. https://doi.org/10.1016/j.cemconres.2020.106097
61. Schniederjans, D. G., 2017: Adoption of 3D-printing technologies in manufacturing: A survey analysis. International Journal of Production Economics, 183: 287-298. https://doi.org/0.1016/j.ijpe.2016.11.008
62. Schubert, C.; van Langeveld, M. C.; Donoso, L. A., 2013: Innovations in 3D printing: a 3D overview from optics to organs. British Journal of Ophthalmology, 98 (2). https://doi.org/10.1136/bjophthalmol-2013-304446
63. Shehata, S. A. E.,: Application of 3D Printing in Interior Design and Furniture. Architecture and Arts Magazine, Fifteenth Issue.
64. Smarzdewski J.; Wojciechowski, W. K.; Poźniak, A., 2018: Auxetic lattice truss cores fabricated of laywood. BioResources, 13 (4): 8823-8838.
65. Steenhuis, H.-J.; Pretorius, L., 2016: Consumer additive manufacturing or 3D printing adoption: an exploratory study. Journal of Manufacturing Technology Management, 27 (7): 990-1012. https://doi.org/10.1136/10.1108/JMTM-01-2016-0002
66. Sun, L.; Zhao, L., 2017: Envisioning the era of 3D printing: a conceptual model for the fashion Industry. Fashion and Textile, 4 (25). https://doi.org/10.1186/s40691-017-0110-4
67. Szilvśi-Nagy, M.; Matyasi, Gy.; 2003: Analysis of STL Files. Mathematical and Computer Modelling, 38 (7-9): 945-960. https://doi.org/1016/S0895-7177(03)90079-3
68. Tao, Y.; Pan, L.; Liu, D.; Li, P., 2019; A case study: Mechanical modelling optimization of cellular structure fabricated using wood flour-filled polylactic acid composites with fused deposition modelling. Composite Structures, 216: 360-365. https://doi.org/10.1016/j.compstruct.2019.03.010
69. Tofail, S. A. M.; Koumoulos, E. P.; Bandyopadhyay, A.; Bose, S.; O'Donoghue, L.; Charitidis, C., 2018: Additive manufacturing: scientific and technological challenges, market uptake and opportunities. Materials Today, 21 (1): 22-37. https://doi.org/10.1016/j.mattod.2017.07.001
70. Top, N.; Şahin, I.; Gokce, H.; 2019: Topology optimization for furniture connection part and production with 3D printer technology. In: Proceedings of 29th International Conference Research for Furniture Industry, Ankara, Turkey.
71. Travitzky, N.; Bonet, A.; Dermeik, B.; Fey, T.; Filbert-Demut, I.; Schlier, L.; Schlordt, T.; Greil, P., 2014: Additive Manufacturing of Ceramic-Based Materials. Advanced Engineering Materials, 16 (6): 729-754. https://doi.org/10.1002/adem.201400097
72. Wahab, S.; Wagiman, A.; Ibrahim, M., 2013: Development of wood-based composites material for 3D printing process. Applied Mechanics and Materials, 315: 987-999. https://doi.org/10.4028/www.scientific.net/AMM.315.987
73. Wechsler, A.; Hiziroglu, S., 2007: Some of the properties of wood-plastic composites. Building and Environment,

42 (7): 2637-2644. https://doi.org/10.1016/j.buildenv.2006.06.018
74. Weller, C.; Kleer, R.; Oiller, F. T., 2015: Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. International Journal of Production Economics, 164: 43-56. https://doi.org/10.1016/j.ijpe.2015.02.020
75. Wimmer, R.; Steyrer, B.; Woess, J.; Koddenberg, T.; Mundigler, N., 2015: 3D printing and wood. In: Proceedings of International Conference "Wood Science and Engineering in the Third Millenium" – ICWSE, Brasov, Rumania, 10th ed., pp. 144-149.
76. Wong, V. K.; Hernandez, A., 2012: A Review of Additive Manufacturing. International Scholarly Research Notices, 208760. https://doi.org/10.5402/2012/208760
77. Wu, T.; Cheung, E. H. M., 2005: Enhanced STL. The International Journal of Advanced Manufacturing Technology, 29: 1143-1150. https://doi.org/10.1007/s00170-005-0001-5
78. Xu, X.; Wu, J.; Tao, J.; Wang, X.; Liu, W., 2019: Research on 3D printing service model for innovation, entrepreneurship and universal applications. Materials Science and Engineering: R: Reports, 140: 100543. https://doi.org/10.1016/j.mser.2020.100543
79. Yeh, C. C.; Chen, Y. F., 2018: Critical success factors for adoption of 3D printing. Technological Forecasting and Social Change, 132: 209-216.
80. Yulvan, Y., 2020: 3D Printing in the learning Process of Furniture Design, Proceedings of the 1st Conference of Visual Art, Design and Social Humanities by Faculty of Art and Design, CONVASH, Surakarta, Central Java, Indonesia.
81. ***Forust, https://www.forust.com/technology; Figure 2 (Accessed Dec. 15, 2021).
82. ***https://3dprint.com/; Figure 2 (Accessed Dec. 15, 2021).
83. ***https://www.printyourmind3d.ca/; Figure 2 (Accessed Dec. 15, 2021).
84. ***https://parametrichouse.com/3d-printed-furniture/; Figure 3 (Accessed Dec. 15, 2021).
85. ***https://ultimaker.com/learn/3d-printing-in-furniture-design; Figure 3 (Accessed Dec. 15, 2021).
86. ***https://3dprinting.com/3d-printing-use-cases/how-the-furniture-industry-benefits-from-3d-printing/; Figure 3 (Accessed Dec. 15, 2021).
87. ***https://3dprint.com/45399/marie-antoinette-museum-chair/; Figure 4 (Accessed Dec. 15, 2021).
88. ***https://www.3dnatives.com/en/3d-printed-furniture-130220194/; Figure 7 (Accessed Dec. 15, 2021).

Corresponding address:

SILVANA PREKRAT
University of Zagreb, Faculty of Forestry and Wood Technology, Department of Wood Technology, Svetosimunska 23, 10000 Zagreb, CROATIA, e-mail: prekrat@sumfak.unizg.hr