Use of 3D Printing in Furniture Production

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Abstract

Innovation is a key factor to survive in today's competitive environment and also is a life-sustaining term about sustainable consumption-manufacturing ratio. Effects of innovation in consumer products that we use at every stage of our lives are clearly seen. While innovation releases more aesthetic, functional and smart/creative (innovative) goods to service for end users, it compels firms (that manufacture these goods) to technological development too. With this technological development, all partners come to a parting of the ways of disruptive or sustainable innovation. Non-industrial use of the 3D printing in furniture manufacturing can be stated as one of the latest innovative development. This handling can cause differentiation of everything from design to material. Convertibility potential to the end goods of everything based on design which starts and evolves in virtual environment can be shown as disruptive side of differentiation. In accordance with this potential, this study aims to make a detailed definition of three dimensional manufacturing, an evaluation of its use for furniture manufacturing within applied projects and create industry-specific awareness.

Key words: 3D Manufacturing, Furniture, Furniture Design, Furniture Production

1. Introduction

Transformation of inputs such as raw material, semi-finished material, machinery, labor, management and investment to the good or service outputs through transformation processes is called production. Manufacturing is the production of goods for merchandise. There are lots of manufacturing types that differ according to the production model and volume and product range. 3D printing is one of these production methods and nowadays getting more attention with "Do It Yourself" concept.

In conventional production, there is movement of material between stations and also materials rotate around their own axis because of cutting, drilling, assembly and so on transactions. This cause waste and leeway. But in 3D production there is almost no wastage and leeway like in conventional systems due to decreased work stations. Goods can be practically finished in a few stations; a computer for modeling and generating the production data, a 3D printer for manufacturing and finishing processes for surface quality. For example if the model is formed with interwoven parts, end products can be finished in a few hours, and finishing time takes a few days depending on surface quality expectations in 3D manufacturing [1]. According to Gibson et al [1] it takes weeks for the same material handling in conventional CNC machining. Because of this speed advantage, 3D manufacturing, is commonly used for prototyping or fixture manufacturing. But according to Winnan [2] more than 20% of 3D manufacturing outputs are end products instead of prototype in 2011 and it's estimated that this ratio will rise to 50% in 2050. According to the Berger [3] in 2012, market size of 3D manufacturing without discrimination of prototype or end good including system, service and material was €1.7bn and it's estimated that market size will be quadruple over the next 10 years. According to Wohlers Report 2013 it was $2.2bn in 2012 [4]. 3D manufacturing cost still considerable higher than the conventional systems for mass production even though the market size grows. For instance, ABS material in

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mass production costs $2 a kilo while $80 a kilo in 3D manufacturing [5]. According to Berger [3] 60% and later on 30% fall is expected about costs for the next 5 years.

3D production may be the next step and the future of modern manufacturing and this idea is becoming significant with this projection. But, craftsmanship is an important factor in furniture production and especially for the classic formed furniture because of the assembly works. Assembly work is an important and time consuming stage in furniture manufacturing. 3D manufacturing can also eliminate this stage due to its production method. Thereby, this study aims to investigate how 3D manufacturing is used to produce furniture within applied projects, which materials and methods used for productions. Also, creating awareness about furniture production by using 3D manufacturing is the minor aim of this study.

2. Materials and Method

Six different 3D printed furniture projects have been examined for this study. These were; 4 AXYZ's realistic looking stool and smart wood, Joris Laarman's puzzle chair, Clemens Weisshaar and Reed Kram's Multithread Escritoire table, Janne Kyttanen's Monarch stools, Laywood-D3 wood based 3D printing filament and Minale-Maeda's 3D printed wood connectors. These applications were examined in terms of production method, assembly, material and design but without any upholstery application.

2.1. Theory

"The use of a computer-aided design-based automated manufacturing process to construct parts that are used directly as finished products or components" definition is used to describe Additive Manufacturing (AM) by Majewski [6] while originally used to describe Rapid Manufacturing by Hopkinson et al [7]. But according to Buswell et al [8] Rapid Manufacturing, Rapid Prototyping, Solid Freeform Fabrication, Additive Manufacturing Technologies entitle the same family of processes.

3D or Additive Manufacturing can use thermoplastic, ceramic, metal alloy, metal matrix composite, stainless steel, aluminum, thermoplastic ceramic or metal powder, paper, metal foil, plastic film, photopolymer materials to form the layers. According to Hopkinson et al. [7] layer forming materials divided into three class; liquid, powder or solid materials by means of the material properties. Selective Laser Melting, Direct Metal Laser Sintering, Selective Laser Sintering, Fused Deposition Modeling, Laminated Object Manufacturing and Stereolithography are the mainly used ones of layer forming methods. All the methods use the same basic processing steps seen on figure 1. CAD modeling is the first and one of the most important processes of the manufacturing because if the model is wrong, end products will be wrong too. This is because end products are manufactured directly from CAD models. Data transformation of the CAD model (Regardless of 3D modeling software used) into the STL (Standard Tessellation Language), OBJ (Object File) or AMF (Additive Manufacturing File Format) formats, slicing the model for laying down material in layers, control and preparation, manufacturing process, finishing works are the basic processing steps for all 3D manufacturing methods as seen on figure 1. Only layer-wise part building and post-processing works differ according to the manufacturing method.

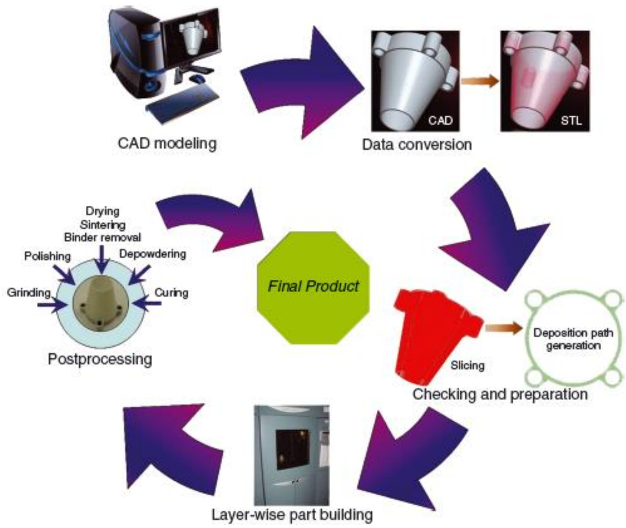

Figure 1. Basic processing steps in layered manufacturing [9].

Fused Deposition Modeling (FDM), as seen in figure 2, uses solid materials like thermoplastic filament or metal wire to melt through nozzle while forming the layer by movement of nozzle according to additive deposition route generated by software after slicing the model. According to Dudek [10] PC (Polycarbonate), PLA (Polylactic acid), PPSF (Polyphenylsulfone) and mix of these are the common used materials after the ABS (Acrylonitrile butadiene styrene) in FDM method. But According to Gibson et al [1] this method has some problems such as processing speed, precision and material density. Also a support material is needed to support the melted material during the cooling. It means that it’s difficult to form stalactite-like designs but according to Celik et al [11] a secondary nozzle can be integrated to deposit stalactite-like designs.

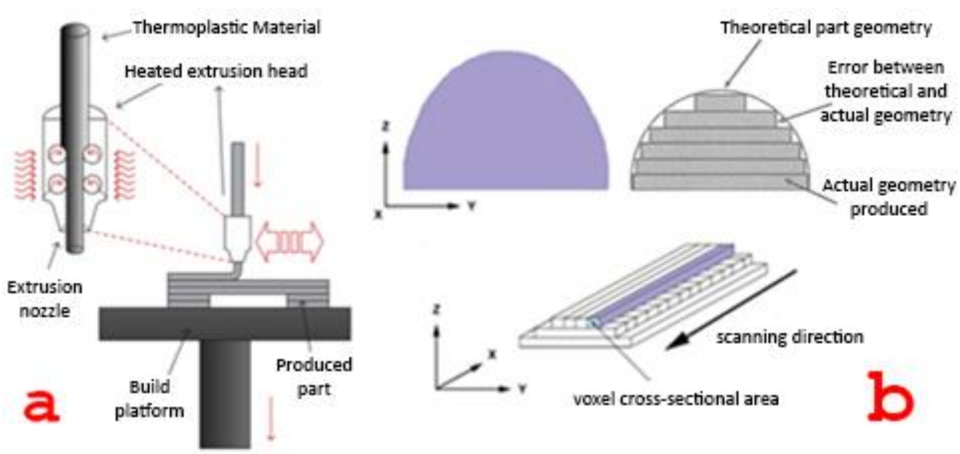

Figure 2. FDM method (a) [12] and layer scanning direction (b) [13], stair stepping effect in AM (b) [6].

3D printers are integral part of the 3D manufacturing systems. They vary in volume, resolution, printing speed and used material. Table 1 shows some of the 3D printers which are generally used for small object manufacturing due to printing volume. But, 3D printers also can print big parts such as chair, table and etc. Figure 3 shows a robotic arm 3D printer, modified from an old automotive assembly line robot, which is designed especially for furniture manufacturing [14]. According to Dehue [15] robotic arm 3D printers are 40 times faster than conventional 3D printers for furniture manufacturing. As seen on figure 3, it has a nozzle with a flexible motion to melt a solid filament for material depositing. But these types of printers are more expensive than others. According to Andres [4] prices of these printers vary between £30000 and £500000.

Table 1. Comparison of some 3D printers [16].

Printers	Volume (mm)	Resolution (dpi)	Speed	Material	Price
RepRap Mendel	200x200x110	.1mm	150mm/s	3mm PLA	$ 830
MakerBot Replicator	225x145x150	.2mm	45mm/s	1.75mm ABS	$ 1750
Ultimaker	210x210x220	.04mm	300mm/s	3mm PLA	$ 1570

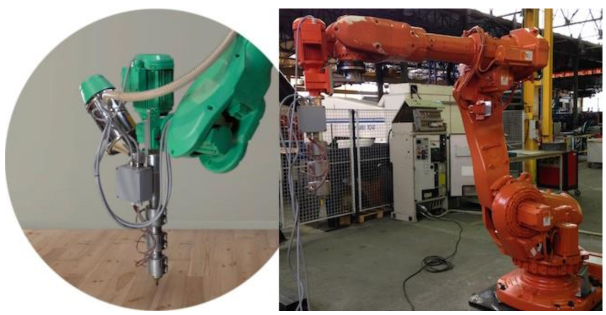

Figure 3 . Galatea robotic arm 3D printer [17].

Resolution is one of the key factors because it defines the shape clarity and dimensional accuracy of product with the layer thickness. According to Dogan [18] accuracy directly affects the surface roughness. Resolution (dpi) and layer thickness (μm) describe the surface quality as well. Layer thickness also depends on layer slicing parameters. Sliced layers of the model and scanning direction can be seen in figure 2b. Printer resolution has an important effect on surface aesthetic too and according to Gibson et al [1] end products need post-processes due to lack of aesthetic and performance. Figure 4 shows an evidence of these disadvantages. According to Lanzetta and Sachs [19] use of bimodal powders provides much improved surface finish. Surface modification is one of the primary concerns and studies are in progress.

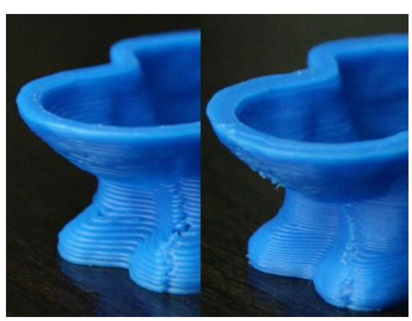

Figure 4. Layer thickness and surface roughness; left is 0,3mm and right is 0,15mm [16].

Selective Laser Melting (SLM) is a powder based method as shown in figure 5b. It fuses the metal powders together with the energy in the form of high power laser beam. Lightweight parts for aerospace industry can be produced with this method. Selective Laser Sintering (SLS) is similar to SLM process and there are two different powder beds, one is for powder supply and the other one is for forming the layers as shown in figure 5a. There is a laser source to select and sinter or melt the material powder as seen in the figure. After each layer formed production bed goes down by movement of the fabrication piston. At the end of production, powder must be cleaned by the help of vacuum system or else to take the product out. There is no need for the support parts to produce end goods by using metal and polymer powders with this method. But laser beam generates high temperatures and because of this products must be allowed for cooling to prevent any formal deformation.

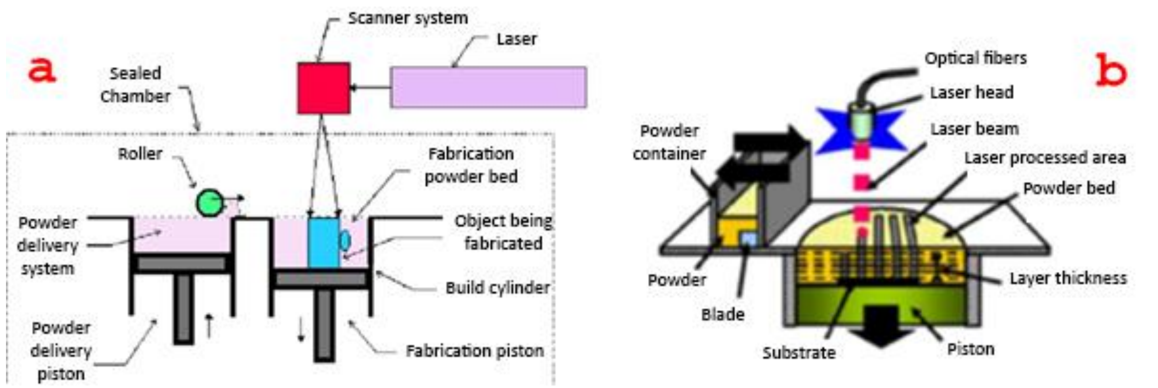

Figure 5. Illustrations of the SLS (a) and SLM (b) [20].

Lamination is one of the methods for manufacturing furniture-look parts due to used material. It can use foils such as paper (new or recycled), plastic foam, ceramic, metal powder impregnated materials. Layers laminated to each other by hot pressing cylinder with the laser beam. But system configuration changes if you use paper. Figure 6a shows configuration of lamination method and figure 6b shows paper lamination technology.

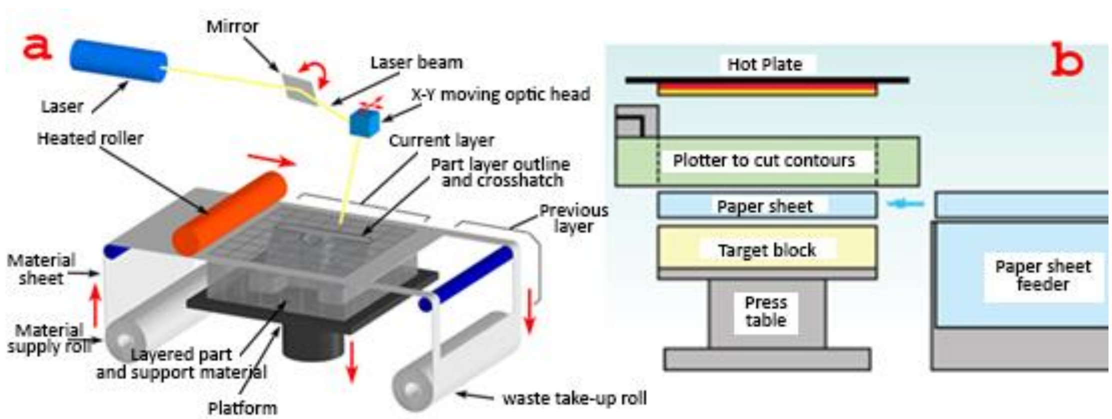

Figure 6. Laminated Object Manufacturing (a) [11; 21] and Paper Lamination Technology (b) [22].

3. Discussion

According to Santos et al [20] 3D manufacturing's main markets are aerospace, automotive and medical industries for rapid prototyping, rapid manufacturing, mass customization and mass production. These markets can be considered as high value adding products' market and products are relatively smaller than furniture. But nowadays production of furniture by use of 3D methods is becoming widespread despite the fact that it's not easy to manufacture real furniture.

4 AXYZ's 3D printed smart wood and stool have real-like surface properties as shown in figure 7. Stool has been printed in three pieces (top and legs) while it may need almost 9 pieces if manufactured by traditional way. Uniformly cut wood pieces combined together to form the layers. According to firm, high labor cost minimized by their trade secret method and consumer has the ability to get customizable furniture in an affordable way within days of order. Stool doesn't have an aesthetic look even if it has real-like surface due to rough design.

Figure 7. 4 AXYZ's 3D printed smart wood and stool [23].

Desktop printers are generally accepted as hobby type printer for small items. This means if you own such a printer you will probably use it to print small accessories instead of furniture. But actually you can have a 3D printed chair with a consumer type desktop printer as shown in figure 8. A puzzle blocks series, simple designed and made from white and black color PLA, were printed out by FDM method to be assembled into a chair. To assemble the pieces together, a proper and strong adhesive must be used.

Figure 8. Puzzle chair printed by desktop printer [24].

Multithread Escritoire table (3D printed (Selective Laser Melting method) aluminum joints, high tensile strength steel tube and powder coated aluminum shelf surface) has a price tag of €45.000 excluding VAT shown in figure 9. It has a special design and branch-like joints that show the strains. Each joint's different color illustration performed by use of finite elements calculations on custom software.

Figure 9. Multithread Escritoire table [25].

Monarch stools are seen in figure 10. It's printed out from glass reinforced polyamide material by Selective Laser Sintering method. It has a ₤9466 price tag for nest of five and a butterfly patterned lattice structure. They stack over each other as other wood or wood-based stools. They look like weak but designed for seating and have 36.5cm height, 36cm width and 37 to 68cm length.

Figure 10. Monarch stools [4].

Accessories seen in figure 11 are made from wood-based (wood/polymer composite, contains 40% recycled wood and unharmful binding polymers [26]) filament by FDM method. Laywood-D3 is the name of the heat sensitive material and looks like cardboard or MDF. Heat sensitive material changes its color by temperature level on the extrusion nozzle. After the production you can sand and then paint it for surface modification. According to Flaherty [26] its painting performance is better than PLA or ABS.

Figure 11. Accessory that has a MDF look-like surface [26].

Wood connectors, seen in figure 12, are made from plastic by FDM method. They can be easily printed by desktop 3D printers and this allows you to assembly preordered components such as simple wood seen on figure 12 with connector you printed. These connectors would make joinery skills unnecessary due to easy use but essential parts like table need to be shipped.

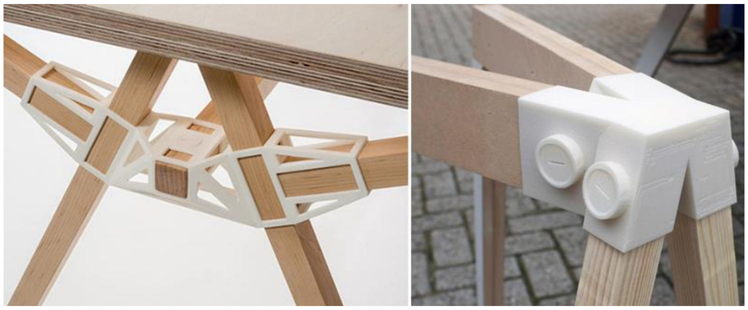

Figure 12. 3D printed furniture connectors [27].

Laser sources generate high temperatures and this can degrade wood material. But wood saw-dusts can be used with Selective Laser Sintering method to transform into a value added goods even if it's suitable especially for metal powder as seen in figure 13. According to Henke and Treml [28] in 3D processes, large scale solids can be printed by using sawdust, wooden chips and etc. as bulk material with gypsum, cellulose, sodium silicate and cement as binder. This also means that contribution can be made for sustainable consumption and production.

Figure 13. 3D printed mask, wood flour (saw-dust) and UF binder [29].

Conclusions

There are material limitations in 3D manufacturing including physical, economic (cost of material and process), environmental and aesthetic (surface quality, color, transparency, texture and etc.) manner. Also mechanical properties should be analyzed before marketing the products. But lots of these materials are more sustainable due to derivation from natural things such as plants. Wood based or wood derived materials become more of an issue because of their naturalness. Wood or wood based materials are the main inputs of furniture industry. As mentioned before, usability of recycled or indigenous materials like wood in furniture production by 3D printing is important for balancing sustainable production and consumption ratio. This is why there is almost no material wastage in 3D production.

It could be impossible to manufacture products that have complex geometries using traditional process in a few steps. But 3D printing allows users to make products which have complex geometries. About production speed, 3D production is relatively slow than mass production techniques and needs to be developed. With 3D production methods, customization comes into prominence and by this means each piece of furniture could be printed distinctly. Also there are free to download open-source designs on the internet. You can modify these designs according to your ideas too.

Finally, 3D production can be assumed as the future of modern manufacturing system but lots of traditional business such as after sales and craftsmanship would be affected positively (for example bringing design works into prominence) or negatively by the potential of it.

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