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Additive Manufacturing Technology in the Furniture Industry: Future Outlook for Developing Countries

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Abstract. For the past few years, the adoption of 3D printing technology has benefited various manufacturing industries, including the furniture making industry. However, this adoption has been greatly seen in industrialized countries and lacking in developing countries. Therefore, to understand fully the capability of 3D printing and its benefits, this paper review discusses recent applications of 3D printing in the furniture industry and assesses the potential it can bring for developing countries' furniture making industry, specifically in the Philippines and other developing countries in Asia. In addition, the drawbacks it brought to the industry, and the challenges that needed to be addressed are also discussed in the paper. The paper covers various 3D printing technologies such as material extrusion, sheet lamination, powder bed fusion, and vat photopolymerization, along with different materials currently used in the furniture industry. Numerous notable examples of applications of 3D-printed furniture are also presented. Based on the review paper, it was found that the most common 3D printing technologies used in the furniture industry are Material Extrusion (MEX) and Powder Bed Fusion (PBF) specifically Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS), respectively. The most common 3D printing materials used are Polyamide (PA), Polylactic acid (PLA), and recycled Polyethylene terephthalate glycol (PETG). The paper also discusses the possible adoption of 3D printing in developing countries and explores its potential to innovate traditional furniture manufacturing processes.

Keywords: 3D Printing, Furniture, Furniture Joints, Furniture Design, Developing Countries

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1. Introduction

Additive Manufacturing (AM) or 3D Printing is a fast-evolving technology that has transformed the manufacturing industry by reducing production time, materials waste, as well as the capability to create objects with complex geometrical shapes [1], [2], [3], [4]. 3D Printing has been revolutionizing the product designs and manufacturing processes in several industries [5], [6], [7], [8], [9], [10], [11], [12], [13], [14] . Recently, a lot of international companies are adopting the 3D printing technology in the prototyping and manufacturing of furniture. Because 3D printing provides flexibility when it comes to design, it can create furniture with complex design in just a few steps. Additive Manufacturing is making a huge impact across the furniture industry, and it is one of the latest innovative developments used in furniture manufacturing [15], [16]. Conventionally, furniture is made using subtractive manufacturing methods that utilize different types of materials to produce the parts. But with a significant trend towards incorporating the 3D printing technology in furniture making, it leads to a broader range of material capabilities, production capabilities, as well as streamlined and systematic production practices that efficiently maximizes time and productivity in manufacturing artisanal products. With 3D printing technologies, furniture manufacturers and designers can produce full size furniture, connectors and joineries, component and replacement parts, and tooling. In addition, customized add-ons can also be produced which can benefit the end-user by creating furniture that is personalized and fits perfectly to its intended use [17]. 3D printing gives the ability to explore new and intricate shapes in addition to a short production time, which is great for economizing labor. However, the adoption of this technology has been greatly utilized commonly by advanced countries, but not by developing countries, like the Philippines and other Asian countries, where the furniture applications of 3D printing technology are still limited. Therefore, to lessen the gap between the adoption of this disruptive technology by advanced nations and developing countries in their furniture industry, it is necessary to understand and identify the key points where the developing countries can gain ideas where they can choose the best way or option for them to adopt 3D printing technology in their furniture manufacturing.

Considering the lack of adoption of the 3D printing technology in furniture making in developing countries like the Philippines, this review paper presents the recent applications of 3D printing in the furniture industry. This will introduce the benefits in innovating the conventional furniture making processes to create better quality products. The 3D printing technology and materials that are currently being utilized in the field of furniture making will be presented. The drawbacks and challenges that are needed to be addressed are also discussed in the paper. However, to limit the scope, the review only focuses on applications of 3D printing in Seating furniture, Surface furniture and Spaces furniture manufacturing. Storage furniture was excluded due to limited applications of 3D printing on this particular type of furniture. In addition, most of the open access 3D-printed designs were not considered in this paper due to limited information about the technology and material used in printing. Generally, this paper would like to create or increase awareness and give insights regarding furniture making using 3D printing, especially for developing countries, like Philippines.

2. Methods

Collection of relevant references and literature were based on the different applications of 3D printing in the furniture industry, how furniture was 3D-printed, and how 3D printing was incorporated to be used for furniture making. Keyword search was used in online scientific journal platforms, such as Science Direct and Scopus, and other online sources. The following key terms were used for the search: “3D printing AND furniture” or “3D printing technology AND furniture” or “3D printing materials, AND furniture” and other more keywords like “additive manufacturing”, were used. Initial evaluation for the inclusion of the relevant paper was based on its relation to the applications of 3D printing in the furniture industry, and irrelevant papers were excluded. Lastly, an in-depth analysis and synthesis on selected relevant papers were conducted. The name of the 3D-printed furniture, its description, the technology and materials used, and the designer were determined and summarized in this paper. A detailed process of steps, keywords, and platforms used for the literature search is shown in Fig. 1 below.

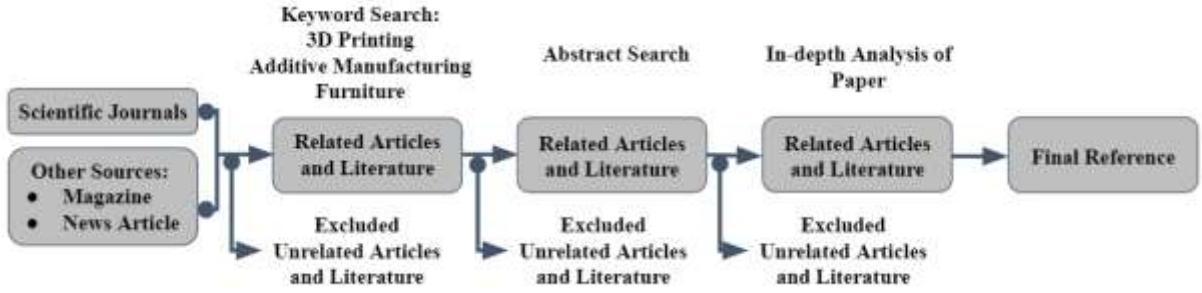

Figure 1. Process flow of the literature search

Within the scope of the study, the use of 3D printing technology in furniture making will be classified and presented according to how much the 3D printing technology was incorporated in the furniture. This will be identified whether the furniture was entirely 3D-printed, or only some component parts, or only its joints or connectors.

3. Additive Manufacturing

The 3D printing process starts with a 3D model which could either be made using a Computer-Aided Design (CAD) software or by 3D object scanners. The 3D model is then converted to a file format such as .STL, .OBJ, etc., and is then processed in a slicing software where the different parameters such as printing speed, layer thickness, infill density are configured [18], [19], [20], [21]. The slicing software is also used to convert the .STL file into a G-code, which the 3D printer uses to create a 3D-printed object [21].After printing, the part will then be removed and post-processed, and will then be prepared for application [19]. The figure below shows the whole process of 3D Printing.

Figure 2. Five (5) general steps in 3D Printing

There are few 3D printing technologies available in the market and they are divided into several types of processes, including Powder Bed Fusion (PBF), Binder Jetting (BJ), Directed Energy Deposition (DED), Material Extrusion (MEX), Material Jetting (MJ), Sheet Lamination, and Vat Photopolymerization [21], [22], [23], [24], [25], [26]. Some of these 3D printing processes are now being widely used in the furniture industry.

4. Build Volume of 3D Printer

Aside from 3D printing processes, the build volume of a 3D printer for furniture manufacturing is another factor that should be considered. Build volume is the maximum dimensions of an object that a 3D printer can create [27]. The size of a 3D printer's build volume varies depending on the its type. Recent innovations on 3D printing technology have made its application in furniture manufacturing more accessible [28]. There are three viable 3D printing techniques based on build volume used in creating furniture, these are desktop 3D printers, large format 3D printer, or Hangprinting [29].

If the project requires creating smaller parts, a desktop 3D printer is the ideal option. Common desktop 3D printers have a build volume ranging from 150 mm to 200 mm cube dimensions. It is an excellent fit for small-scale manufacturing companies. And since the cost of each 3D printer heavily relies on the size of its build volume, desktop 3D printers are considered a cheaper 3D printer [17]. However, most desktop 3D printers are based on the Fused Filament Fabrication (FFF) technology, and other 3D printing technologies are usually of the industrial size (relatively larger). Therefore, if a manufacturing company wants to use another type of 3D printing technology aside from FFF (if they

want to use other materials or for whatever reasons), they need to use a larger industrial 3D printer which is much more expensive [30]. Although it is expensive, having large industrial 3D printers can also give them the capability of creating full-scale models and large prototypes or production parts for a various application which includes furniture manufacturing. Most large 3D printers have dimensions that are approximately 300 mm on one side and around 150 to 300 mm on the other two sides. Aside from the ability of large 3D printers to build large 3D objects, it can also print using pellet extrusion systems [31]. However, large 3D printers are incredibly expensive making it inaccessible for most individuals. Whereas, a hang printer incorporates a relatively new technique in 3D printing furniture. The Hangprinter is an open-source printer, which was designed by Torbjørn Ludvigsen, and is intended to 3D print large objects as affordable as possible. Unlike most 3D printers which print within an enclosure, the Hangprinter is a frameless 3D printer mounted on a room's ceiling. With this, the set-up allows the maximum print volume as big as the room allows [32], [33]. The effector of the printer is suspended from the ceiling and moves with aid of stationary motor with rigid wires and pulleys. It used a network of wires and computer-controlled pulleys that are attached to the ceiling, floor, and walls [34]. Hangprinting is the most accessible and most economical method of creating fully 3D-printed furniture.

5. 3D Printing of Furniture

Despite challenges to manufacture whole furniture, the use of 3D printing in the industry is becoming widespread. Nine (9) different 3D-printed furniture projects have been examined for this study, three for each classification based on the percentage of 3D-printed components of the furniture, whether it was entirely 3D-printed, or only some components were 3D-printed, or whether only the joineries or connectors have been 3D-printed. The 3D-printed examples are as follows: 3D System's Lounger, Print Your City's Recycled Furniture XXX bench, One_Shot stool, Glass top Rio side table, Zortrax's Karo 3D-printed coffee table, Bits and Parts' Maker Chair Puzzle 3D, Minale-Maeda's Keystone dining table, Jon Christie's Saul Dining Table and Chairs, and Alexandre Chappel's 3D-printed chairs. The furniture was examined in terms of manufacturing method, materials, design, and assembly

5.1. 3D Printing of Whole Furniture

First example is a lounge called "Sofa So Good." It is a single piece 3D-printed furniture fabricated using the ProX 950 SLA printer, one of the largest large format 3D printers by 3D Systems. The design mimics the natural structures like silkworm cocoons and spiderwebs. It is a diamond mesh-like structure lounger measuring 150 cm in length, 75 cm in width, 55 cm in height and weighing 2.5 kilograms that was designed geometrically to provide maximum strength from as little material as possible and to hold up to 100 kg of weight. Using stereolithography (SLA), a total of 6,000 layers with a measurement of 99 micrometers thick were printed layer-by-layer for over several days using 2.5 liters of photo-reactive resin material. Afterwards, it was coated with copper and chrome plating to attain the desired finish. The designer emphasized the capability of the 3D printing technology to create complex furniture designs and ensure a more economical way of using materials [35], [36].

Another example is the "XXX bench." In 2017, as part of the "Print Your City" project, the research and design studio The New Raw, located in Rotterdam, is using recycled plastic to create 3D-printed street furniture and equipment. The XXX bench is the first 3D-printed furniture produced from this project that was fabricated in collaboration with Aectual using a large-scale pellet extrusion 3D printer. Each bench is made of pellets from municipal plastic waste or flakes from ground-up plastic products made primarily from Polypropylene (PP) and Polyethylene (PE) plastics. And it is entirely 3D-printed using a single material which makes it robust furniture, and 100 % recyclable at the end of its service life. This twisted bench weighs 50 kg with a length of 150 cm and a width of 80 cm. The XXX bench was designed to form a giant double-sided rocking chair that can accommodate two to four people [37].

The third example is "The One_Shot stool" designed by Patrick Jouin for the MGX Project by Materialise. It is a functional stool with a dynamic structure manufactured as one complete piece. Its seating surface and legs, and all moving parts and hinges, are concealed within the structure, and are 3D-printed together or in "one shot." It is 3D-printed using Selective Laser Sintering (SLS) with

polyamide (PA) powder material. With an easy twisting motion and gravity, the stool will collapse, much like an umbrella, for storage or transportation [38]. Table 1 shows more examples of a whole 3D-printed furniture:

Table 1. Some Examples of Whole 3D-Printed Furniture

Designer	Material	Technology	Classification
Patrick Jouin	Lacquered Epoxy Resin	Stereolithography (SLA)	Seating Furniture
Solid C2 Chair is created using a digital process featuring an elegant interconnected lines resembling the appearance of natural structures in sketches [34].			
Alejandro Estrada of Piegatto	Biodegradable and weatherproof PLA, wood composite pellets	Delta WASP 3MT INDUSTRIAL 4.0 pellet-based FDM 3D printer	Seating Furniture
Truss Chair is a 3D-printed white chair weighing around 250lb representing the true essence of plastic with a durable Ingeo-biopolymer [39].			
Zaha Hadid Architects for Nagami	PLA plastic	Large-scale pellet extruder robotic 3D printing	Seating Furniture
Bow and Rise chair's design uses a structural optimization process found in nature, with their materials and fabrication methods expressed in the pattern and color gradient of both pieces [40]			
Ross Lovegrove for Nagami	--	Material extrusion-based robotic 3D printer (The Robotic)	Seating Furniture
Robotica TM stool is a high stool with a heat-proof silicone seat inserts with 360^{O} formal access. It can be easily converted into as a dining table, as a TV plinth, or as a stand-alone home decor [41].			
Daniel Wildrig for Nagami	Recycled PETG Polymer	Fused Deposition Modelling (FDM)	Seating Furniture
Peeler chair have three parts giving the illusion that they are separating using an invisible joint [42].			
Manuel Jiménez García	Recycled PETG Polymer	Fused Deposition Modelling (FDM)	Seating Furniture
Nobu Chair embodies regularity, smoothness, as well as moderation, arrhythmia, and madness [43]			
BigRep's Beatrice Müller	--	BigRep's One FDM 3D printer	Seating Furniture
Ocke Series chair and sofa were designed based on trees and leaves needing no additional support and it grows out of themselves [44]			
Janne Kyttanen of Freedom of Creation	Glass filled Polyamide	Selective Laser Sintering (SLS)	Seating Furniture
Trabecula Bench's design draws inspiration from the low-density inner structure of bird bones making a structure that is very lightweight but incredibly strong. [45]			
Janne Kyttänen of Freedom of Creation	Glass reinforced Polyamide	Selective Laser Sintering (SLS)	Seating Furniture
Monarch Stools showcases organic yet decorative lattice designs, comprising five unique stools with varying sizes that can be stacked together.[46]			
Lilian van Daal	Polyamide	Selective Laser Sintering (SLS)	Seating Furniture
Biomimicry Chair is made of plastic that imitates the plant cell structure of the natural world [47]			
Sofia Hagen and Lisa Hinderdael of	r-PETG recycled from medical tray waste	Large-format material extrusion-based 3D printer made of Ai Build robotic	Seating Furniture

HagenHinderdael Studio		systems using AiSync software	
Twine is wave-like form seat or elongated bench which has been designed playfully creating a varying way to sit on it [48].			
Dirk Vander Kooij	recycled plastic from refrigerator	Material extrusion (Fanuc)	Seating Furniture
Endless Chair is crafted from a single continuous piece of plastic string derived from old refrigerators that can be used to create chairs of various sizes, shapes, color gradients, or stripe patterns.[49]			
Emmanuel Touraine of Ventury Paris	--	Stereolithography (SLA)	Seating Furniture
Eiffel Tower Chairs are chairs that resemble the structure of Eiffel tower in Paris [50]			
Emmanuel Touraine of Ventury Paris	--	Stereolithography (SLA)	Seating Furniture
Organic Functional Sculpture 'Gaudi' bar stools and chaise lounge are both 3D-printed in one piece using SLA technology and then cast in bronze[50]			
Emmanuel Touraine of Ventury Paris	--	Stereolithography (SLA)	Surface Furniture
Organic Functional Sculpture 'Gaudi' Side Table are bronze-cast 3D-printed side table designed based on an organic cellular pattern. [50]			
Verner Panton	Non-toxic biodegradable PLA plastic pellet from renewable resources	Material extrusion-based robotic printing arm	Seating Furniture
Voxel Chair is created using a 2.36 kilometers long continuous stretch of transparent plastic mixed with blue particles that generates a color gradient [51].			

5.2. 3D Printing of Furniture Component Parts

First example is a glass top Rio side table, designed in collaboration with Architect Mehran Gharleghi of studio INTEGRATE and Morgan Studio. This furniture integrates traditional furniture materials like wood and glass with 3D printing technology to create an intricate curved sculptural feature that is an essential part of the design. The 3D-printed component of this Rio side table forms a basket-like structure that links the timber legs to the glass top, which was carefully designed entirely through a mathematical algorithm. The design maximizes the amount of material utilized while ensuring that the structure will withstand weight, creating a distinctive and exquisite design. The component of the Rio side table was 3D-printed from polyamide powder using SLS technology. The component was printed with all the necessary drillings required making it ready for final assembly once post-processing was done. In addition, the polyamide component as well as the rest of the table is fully recyclable [48].

The next example is Karo 3D-printed coffee table. It was manufactured by a Poland-based 3D printer manufacturer Zortrax, to showcase how Additive Manufacturing could change the approach in furniture manufacturing. Karo 3D-printed coffee table is a sleek-looking and perfectly balanced piece of furniture with a 3D-printed base with glass on top. The base was constructed from several diamond-shaped and triangular modules entirely 3D-printed using a Zortrax M200 desktop 3D printer. Thus, its base was 3D-printed in several sections using three different colors of Zortrax's Z-ULTRAT filament. Z-ULTRAT filament is an ABS plastic blend designed to have durability, excellent surface quality, and resistance to high temperatures and high impact suitable for end-use parts or consumer products like this furniture. Its 3D-printed base used 3,171 grams of filament and completed in 262 hours and 32 minutes. The glass on top of the 3D-printed base weighing 7 kg resulted in a solid and quite heavy coffee table. In addition, because it was manufactured from thermoplastic material, the table could be used either as an indoor or outdoor furniture[49-50].

With 3D printing, the door is now opening for small furniture designers to make numerous unique

and creative ideas. One of them is the first crowd-fabricated 3D-printed chair called Maker Chair Puzzle 3D. It was first released by an Amsterdam-based lab founded by Joris Laarman, Bits & Parts. This chair comprises of puzzle pieces that can be created with a desktop FDM 3D printer using plastic filaments. The 85 interlocking puzzle pieces of the chair are 3D-printed individually and assembled afterward. Each piece was carefully designed, tested, printed, assembled, and retested. Then its STL files were uploaded to the designer's website so the end consumer could download the STL files, allowing anyone with a basic knowledge of the 3D printing process to reproduce it. In addition, to make the entire process go smoothly, they also share the print settings used: PLA with the filler at 25% and printing speeds of 90 mm/s and 150 mm/s at a temperature of 220 °C. They also describe how 3D-printed parts will be set upon a base made of a wooden rod and greenhouse brackets [54]. The idea of printing furniture parts into several pieces makes it possible for users of desktop 3D printer with small build volume and cannot afford to print large objects such as side coffee tables and chairs. Table 2 shows some examples where furniture component parts were 3D-printed:

Table 2. Some Examples of 3D-Printed Furniture Component Parts

Designer	Material	Technology	Classification
Reed Kram and Clemens Weisshaar of Multithread	Aluminum	Selective Laser Melting (SLM)	Surface Furniture
Escritoire Table have a branch-like joints supporting the flat surface of furniture optimized using a custom software that "analyzes, modifies, and paints" the joints according to the forces they are subjected [55].			
Aleksandrina Rizova of ALEKSA Studio	--	3D Print UK using a Selective Laser Sintering (SLS)	Surface Furniture
Transitional Fields Table have legs that are lightweight and highly efficient foundation that can withstand a large amount of natural wood on top [56].			
Model No. Furniture	Eco-Resin PLA	Large custom-built material extrusion-based 3D printer	Surface Furniture
117 Side Table: Lounge is a piece made with a low-slung design with dramatic curves with height perfect for lounging [57]			
Neri Oxman	44 composites that are combinations of three synthetic rubber-like plastics	Stratasys Objet500 PolyJet 3D printer	Seating Furniture
Gemini Alpha is a multi-colored chaise lounge with 44 distinct composite materials that were 3D-printed inside a wooden frame[58].			
Maria Cichy	--	Selective Laser Sintering (SLS)	Seating Furniture
Chrisco Chair is a rotating chair with 3D-printed shell having complex spider web pattern. The shell comes with clip-ons so a leather seat pad can be easily attached and placed on top of the shell [59]			
MIT's Self-Assembly Lab, Steelcase and Christophe Guberan	Hard plastic or flexible rubber	Rapid Liquid Printing.	Seating Furniture
Turnstone Bassline Table is a piece with lace-like top manufactured using an experimental process called rapid liquid printing [60].			
IKEA	--	--	Seating Furniture
Ubik Gamer Chair is customized gaming chairs with 3D-printed mesh seating pad inserts based on the customer's biometric data which will be inserted or slid into the seat [61].			

Thorsten Franck Wilkhahn	Lignin	--	Seating Furniture
Printstool One is an hourglass-shaped stool with cushioned top, textured column, and rounded base [62].			

5.3. 3D Printing of Furniture Component Parts

A joinery is a connecting mechanism that joins wood pieces to produce multipart structures. With traditional woodworking, joinery is only as good as the craftsman's manual chisel ability or the machine's capabilities. But in 2012, a Dutch design studio Minale-Maeda created a Keystone dining table requiring no screws or traditional joinery to assemble. Instead, this furniture, composed of an entire plywood sheet and a standardized saw-cut wood, uses 3D printing to create joineries, into which multiple wooden components or beams can be inserted. The connectors hold the inserted wooden component in place by relying on a simple blunt clamping screw to form structures that can be quickly disassembled. It also prevents the wood from deteriorating when disassembling and reassembling, since no screws penetrated it. The connecting joineries were printed using SLS technology from a polyamide material, the same technology and material used in the Rio side table. Aside from design considerations that optimize the strength and save material used, these connectors also show the structures within the connector that give the furniture a geometric edginess [63].

Another example is Jon Christie's Scandinavian-inspired dining table and chairs which combines 3D printing with traditional furniture manufacturing techniques. This furniture was created by taking a Scandinavian design with his traditional craftsmanship and by adding smartly modeled 3D-printed joints, allowing greater customization in color and shapes, quicker production time, and reducing waste production. In addition, with 3D-printed joints, the furniture can be delivered to its destination in several pieces allowing cheaper distribution. The Rhinoceros software was used in the 3D modeling of each joint and 3D-printed using the FDM technology of Ultimaker. The 3D-printed components were made from polyamide material with a natural white color that offers a good contrast against the walnut highlighting the connections. Every single component of this furniture has a function and a product of blending traditional craftsmanship, modernist design, and 3D printing technology, creating pieces that are flexible, stylish, and more importantly, economical [64].

Like Jon Christie's project, a Norwegian YouTuber and industrial designer Alexandre Chappel created his own wooden furniture with 3D-printed joints [65]. His furniture was constructed using conventional hand tools, wood, and a 3D-printed joints. However, unlike Keystone dining table which uses SLS 3D printers, Alexandre Chappel uses a material extrusion-based 3D printer which is significantly inexpensive compared to the former [66]. Thus, the way that Alexandre Chappel's chair and Jon Christie's table and chairs were built is an ideal point of entry for small furniture makers, in terms of practicality. Other examples of 3D-printed furniture joints are shown in Table 3.

Table 3. Some Examples of 3D-Printed Furniture Joints

Designer	Material	Technology	Classification
James McNab, Sam Griffin and Daniel Kamp of Y.S. Collective	Titanium Powder	Selective Laser Sintering (SLS)	Surface Furniture
Titanium-Tawa Table is a lounge table with several levels with 3D-printed Titanium connectors and hand-carved New Zealand Tawa wood [67]			
Tong Jin (TJ) Kim	--	--	Space Furniture
The Joint Table is a 3D-printed table providing simple and easier method of furniture making [68].			
Design Hybrids Lab	Nylon-12	Selective Laser Sintering (SLS)	Seating Furniture
Digital Joinery is Voronoi diagram skeleton joint joining four wooded beams of a hybrid stool. The joint is designed and created using a software for generating digital joints [69].			

6. Discussions

Based on the examples cited, it can be observed that industrial 3D printers that can entirely produce 3D-printed furniture are quite expensive, this is one of the main reasons why the developing countries cannot easily adopt this technology. Hence, there are no notable 3D-printed furniture manufactured in developing countries that came up during the literature search conducted for this paper. However, with advancing technology and falling prices in recent years, local material extrusion-based desktop 3D printers are now available in the Philippines are around Php 10,000 to Php 30,000 (approx. $170 to $511) [70]. However, these 3D printers are only good for a shorter period, unlike the high-grade or sophisticated industrial 3D printers that can last up to several decades [71]. In addition, these low-cost 3D printers produce low quality products which is why 3D printer applications in the Philippines are only utilized for prototyping rather than real-life applications, specifically for load-bearing parts or products like furniture. To address this problem brought by costly industrial 3D printers and low quality local 3D printers, this paper shows a solution on how to maximize the use of the local desktop 3D printers to still produce high quality products that can at least compete with the quality of products produced by industrial 3D printers. The reason why material extrusion-based 3D printers has been highlighted in this section is because it is the best technology to start with for the Philippines' furniture making industry, as it is the most common and widely available 3D printing technology in the local market [72].

In addition, the examples mentioned previously show the viable way to introduce 3D printing in the furniture industry is to create furniture by 3D printing parts by parts. With this method, furniture from developing countries can produce either furniture with 3D-printed components or parts, like Karo 3D-printed coffee table and Maker Chair Puzzle 3D, or furniture assembled with 3D-printed joints or connectors, such as Jon Christie's dining table and chairs, and Alexandre Chappel's chair. However, aside from the cost consideration of the 3D printer, it is also important to train the traditional designers of the furniture industry with additional skills to become design engineers to better use 3D printing in the design and manufacturing process. Furniture designers not only need to master their design skills but also need to have expertise in some knowledge and skills in related disciplines and engineering fields.

7. Conclusion and Further Research

This paper presented and examined the different applications of 3D printing in various furniture projects which were classified as, Seating furniture, Surface furniture and Spaces furniture. It determines the extent of incorporated 3D-printed parts in each furniture, whether it is entirely 3D-printed, only some component parts, or only its joints or connectors. Numerous examples of 3D-printed furniture from international designers have been cited in this paper (see Table 1 - 3). Some of which were critically examined to further study the 3D printing technology used and the materials used (and its properties) in the production of the 3D-printed furniture. Based on the numerous examples of 3D-printed furniture from international designers that we have been gathered and examined, it was found out that the most common 3D printing materials used in the furniture industry are Polyamide (PA), Polylactic acid (PLA) and recycled Polyethylene terephthalate glycol (PETG). Common 3D printing technologies are Material Extrusion (MEX)) and Powder Bed Fusion (PBF) specifically Fused Filament Fabrication (FFF) / Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS), respectively.

It was also determined that the extent of 3D-printed parts in the furniture can influence what the classification of furniture it can create. If the whole furniture was 3D-printed, then it most likely to be a Seating furniture. If only some component parts of furniture were 3D-printed, it could produce either a Seating or Surface furniture. Lastly, if only the joints of the furniture are 3D-printed, it could be any of the three classifications of furniture: Seating, Surface, or Space furniture. Additionally, 3D-printed joints are commonly produced using Polyamide material and SLS technology. Given that furniture with 3D-printed joints seems to be efficient across different classification of furniture and its creation typically does not require a large format 3D-printer which is expensive, this suggests that it has a great potential for integrating the 3D printing technology into the furniture industry of developing countries, like the Philippines. Since international designers have been incorporating 3D printing in the furniture industry

and proved that this technique is feasible and usable, local adaptation of this technique may be considered in the improvements of locally designed and manufactured furniture from the developing countries like the Philippines. With this, the following should be considered for further research:

- To identify the designer's role in generating 3D models and creating the optimal design of the 3D-printed furniture which may be entirely 3D-printed, with 3D-printed component parts, or with 3D-printed joints or connectors.
- To determine the property of the material that will be incorporated in the design and fabrication of the 3D-printed furniture.
- To incorporate the design method and manufacturing for the design and fabrication of the 3D-printed furniture.
- To create requirements or standards in future applications of 3D printing in the furniture industry.

3D printing has the capability to significantly change products and the way they are manufactured. In order to execute this technique of incorporating 3D printing in the furniture industry, identification of methods in designing and fabricating the 3D-printed furniture should be considered, which this work serves as the first step.

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