Sustainable Furniture Joints: Leveraging Fused Deposition Modeling (FDM) for Eco-Friendly Design

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Abstract. Integrating form, function, and material selection has been fundamental in furniture design and production. Traditional methods, particularly in joint creation, demand skilled craftsmanship and time-intensive processes. However, the emergence of 3D printing technology, specifically fused deposition modeling (FDM), has revolutionized furniture joint production. This study investigates the sustainable application of FDM for creating furniture joints, emphasizing eco-friendly design and efficient material utilization. To optimize the joinery system using 3D printing, researchers have conducted structured interviews with experts in the Malaysian 3D printing field. Their insights guided the development of guidelines for selecting appropriate materials and optimizing joint geometries. In furniture manufacturing, FDM enables precise joint components through layer-by-layer construction using thermoplastic materials. Unlike traditional methods that often result in wood waste, FDM minimizes material consumption. Designer-generated joint designs produced seamlessly via 3D printing reduce production time and enhance precision. Cost-effectiveness further positions FDM as a sustainable alternative for furniture production. This research focuses on two commonly used FDM materials: Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA). By providing guidelines for selecting appropriate materials, it will eventually empower designers and manufacturers to create furniture joints that align with sustainability goals. The resulting joints exhibit superior accuracy compared to manual craftsmanship, contributing to both environmental conservation and innovation within the Malaysian furniture industry

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1 Introduction

As the world faces the challenges posed by global climate change, it becomes increasingly crucial to understand and address the effects of environmental factors towards any area of processess [3]. 3D printing is a way of producing solid a three dimensional items in diverse forms from digital designs [15]. This approach speeds up the manufacturing process and allows for large-scale production. This sustainable approach is anticipated to offer viable resolutions for addressing fundamental human necessities, fostering economic progress, attaining social equity, and safeguarding the environment [17]. The Malaysian furniture industry's challenges include high material waste, labour-intensive organic shape design, and difficulties in handling and storage for transportation [3]. 3D printing reduces waste compared to traditional crafts methods that involve material removal by cutting or drilling. A 3D printing technique commonly used in the furniture industry is the FDM, which builds furniture joints by depositing appropriate layer prints [17].

Furthermore, prior to printing with 3D printing machines, the design process for making 3D items includes product sketching with a variety of software tools [5]. Designers just need to develop a single design draft using software like AutoCAD, SolidWorks, or Rhinoceros before mass fabricating furniture joints. As a result, Computer-Aided Manufacturing (CAM) seeks to computerise the design and execution processes that translate designs into finished goods.

A computer-controlled 3D printing system efficiently produces furniture joints from 3D printing materials. The 3D printing technique uses a computer-controlled nozzle to command movements along several axes, such as x and y, or according to geometric shape [18]. This method allows rapid and precise production of furniture joints.

Concurrently, furniture design studies have demonstrated a significant boost to the user value of wood-based furniture goods [4]. Furniture joints are necessary for creating robust furnishings designs. These well-designed furniture pieces attempt to harmonise human behavioural relationships with shape, function, and significance in the final product according Abdullah [9]. Dowels are usually used in rectangular furniture and mainly on round dovetails. This is because of its directness and cheap price in the manufacturing process [9]. Carpenters' conventional use of furniture joints frequently demands a significant amount of patience to finish every component. As a result, any furniture joints that use the dovetails technique and materials can be used in 3D printing, which is a must in the emerging design of modern creation.

The purpose of this research is to discover and elucidate the durability of the joints in furniture industries using suitable substances by 3D printing focusing on FDM. Furthermore, the research seeks to prepare proper guidance in FDM to develop furniture innovatively. This will serve as a guideline to measure the suitable temperature to imply extrusion technique in order to achieve a high-class quality of surface on products. In high-quality furniture manufacturing, the joints are the essential component. Users anticipate aesthetic value, utility, and dependability in furniture creation. However, this feature presents difficulties for carpenters and frequently requires extensive operations. 3D printing speeds up these operations and

makes it easier to resolve complex jointing jobs. Researcher will analyse design components to create guidelines for the design of joints using FDM technology.

2 Methodology

This study employed a qualitative approach, involving interviews with three respondents from different companies. These respondents, representing companies A, B, and C, are involved in the production of products using 3D printing technology. Each respondent has on average, six years of experience in 3D printing activities. The researcher recruited 3 of interviews has experience in producing various products using 3D printing. Sharing the experience they have will helped the researchers to coplete this study by producing a framework tahat can be a guide to thr reader for the selection of the right material to produce furniture joints combined with wood material. Data were recorded, and interviews were conducted within a one-month period. The study utilised thematic analysis organized by themes. Interview questions were categorised into three sections to gather information on filaments, types of furniture joints, and finishing methods for 3D printed products. Insights were also gathered from three experienced respondents who use 3D printing materials in product manufacturing. These respondents contributed to the data analysis.

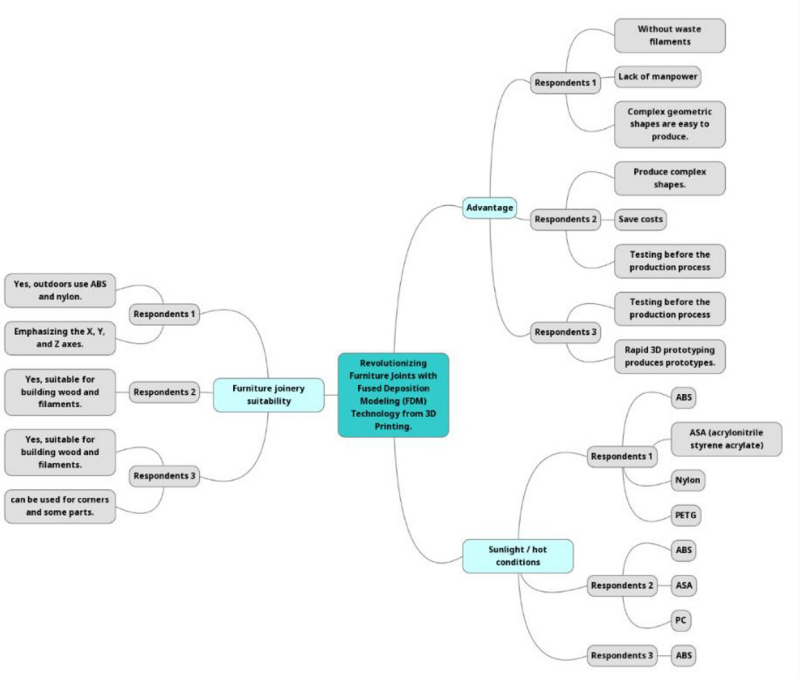

Figure 1. Domain segments derived from survey questions.

3 Analysis

3.1 Advantages of 3D printing technology in product manufacturing

The furniture design sector benefits profoundly from 3D printing technology. The use of plastic and wood materials represents a novel breakthrough in furniture manufacturing. Furniture designed using Computer Aided Design (CAD) technology not only accelerates the design and improvement processes but also necessitates consumer adaptation to emerging furniture forms during the design phase according [6]. Interviews with 3D printing respondents as stated in figure 1, in advantage section revealed that complex geometric shapes can be created more easily and efficiently compared to traditional techniques. 3D printing replicates designs exactly as envisioned in CAD, facilitating high-volume production from a single design layout.

Furthermore, the second second respondent stated that the use of 3D printing technology reduces waste compared to traditional methods, where the 3D printing machine deposits material only as needed to shape the final object designed in software such as AutoCAD, Rhino, or Solidworks. Designs are created in AutoCAD and then transferred to Computer Numerical Control (CNC) for wood cutting using computer-generated files [11]. In modern procedures, 3D printing machines replace manual equipment, saving time and cost while also utilising materials more efficiently. FDM technology is more popular than other methods due to its ease of production, cost-effectiveness, and environmental friendliness [8]. Professional designers use 3D CAD software for 3D prototype printing and rapid manufacturing to create structures, furniture, and models [13]. Figure 2 shows an example of a shelf that has been produced jointing using 3D printing technology.

Figure 2. Hexagon Shelf Crafted Using 3D Printing Technology.

3.2 The performance of 3D printing filaments under sunlight exposure.

FDM and Stereolithography (SLA) are the two main technologies utilised in 3D printing. The evolution of 3D printing began with SLA technology. FDM often has more economical production costs than SLA, depending on the product's unique use. However, for achieving durable furniture joints, FDM technique is more ideal. FDM inherently features layered construction for each part, unlike SLA, which is as fragile as glass and susceptible to fracturing upon impact. FDM technology includes several filaments. Examples include ABS, polyethylene terephthalate glycol (PETG), and PLA. The choice of filament depends on the application and working environment for the product. Finally, the required process parameters are set within the 3D printer according to the filament material used [14]. In prototyping, PLA is commonly used for testing before final furniture production. PLA is considered the least expensive filament and is a bioplastic derived from renewable sources such as maize, potatoes, and sugarcane [14].

Therefore, furniture that requires high temperature resistance for indoor or outdoor installation is suitable for materials such as PETG, ABS, nylon, or polycarbonate (PC). 3D printers using FDM technology build components layer by layer from bottom to top with thermoplastic filaments, through heating and deposition [18]. PLA and ABS are among the filaments suitable for producing small products because of their plastic strands woven into coils. Figure 1 dirived from survey question shows that all three respondents choose ABS filament as a suitable material exposed to the sunlight or hot conditions. Before starting 3D printing, designers must understand the material's applications and the environmental criteria for furniture use. This figure 3 shows a product that uses ABS filament.

Figure 3. Types of ABS filament.

3.3 The compatibility of filaments for furniture joints.

3D printing is ideal for use in furniture joints because it combines two materials, plastic and wood. Given the difficulties, time commitment, and extensive workmanship involved in traditional furniture assembly methods, replacing wooden joints with 3D printed connectors provides a substantial advantage [16]. Furniture made from these two materials can use the mortise and tenon principle, allowing customers to self-assemble, similar to IKEA's ready-to-assemble (RTA) model. Screws, nails, bolts, and dowels are often used in contemporary furniture built for RTA as it was connected by external fasteners [19]. The usage of the items gives benefits to the public as the complicated technique of mortise and tenon joint preparation and attachment can be disregarded and save time [16].

The results of the interview in figure 1 indicate how to achieve sturdy furniture joint construction, the product designer must first examine the strength angles of each component. The components x, y, and z have different angles and strengths. The z-axis tenon is much weaker than the tenons of the x and y axes, which makes it indispensable in furniture design. 3D printing filaments are frequently employed in the fabrication of small ABS support structures. Rapid prototyping FDM systems offer versatility by enabling the production of parts from various materials, including elastomers, ABS, and lost wax investment casting according [7]. Research suggests that ABS and nylon filaments are ideal for furniture joints, given their compatibility with various indoor and outdoor weather conditions.

4 Findings and discussion

4.1 Usage of 3D printing materials for furniture joints.

Additive manufacturing in modern furniture uses 3D printing materials for furniture joints. The combination of materials, plastic and wood are a unique and mind-blowing concept in the industry. In furniture joints, 3D printing material is famous as it is way simpler to construct joints with complex geometric shapes. Furthermore, 3D printing can manufacture a variety of shapes depending on designs created in CAD software. In figure 4 below briefly shows about advantages of 3D printing, suitable filament types, compatibility of materials with the environment, and the process of using 3D printed furniture joints

The most prevalent 3D printing method is FDM. PLA, ABS, PETG, and PC are common 3D printing materials used with FDM technology, with ABS

being the most preferred among companies A, B, and C. This inclination stems from interview results identifying that ABS filament are weather-resistant and suitable for both indoor and outdoor use. FDM technology is preferred for furniture joints due to its layered structure. The manufacturing procedure entails layer-by-layer deposition to obtain the desired shape. SLA technology, on the other hand, is brittle, smooth, and easily broken, much like glass.

The printing process varies according to the speed of the machine. However, each machine may produce items based on the materials used and can be regulated by software settings to speed up the process. FDM technique can be accelerated because of its layer-by-layer deposition procedure, which may cause lines on the product's surface. Furthermore, scaling up 3D printing equipment is a way to speed up product manufacture. Scaling up 3D printing machines and utilising them simultaneously for the production process.

Designers can work more efficiently with 3D printing technologies. Prior to beginning the printing process, furniture designers just need to design on CAD software such as AutoCAD and SolidWorks. When there are problems with the furniture joint assembly process, designers merely need to change the design created in AutoCAD software. This technology facilitates the production of furniture in a timely, orderly, and high-quality manner.

4.2 Types of furniture joints using 3D printed molds.

Advanced additive manufacturing technologies used in furniture production help designers create new product design concepts without limiting shape, number of joints and size. The results of the interviews indicate that respondents agree to combine two materials, plastic and wood, to produce high-quality furniture. In addition, 3D filaments are suitable for the creation of furniture joints, whether for angular connections or other partial components as well. Normally used for smaller products as supports, PLA filament is suitable only for indoor use, as it degrades when exposed to sunlight and is relatively brittle, although it is cost-effective. In contrast, ABS filament has been identified as the preferred material for furniture joints due to its durability for indoor and outdoor applications.

Furthermore, the difference between 3D printing and handmade craftsmanship is that the latter requires highly competent furniture carpenters, a skill that today's generation deems difficult to master, particularly in woodworking. In contrast, 3D printing relies heavily on CAD expertise. Designers that use CAD and CAM software such as AutoCAD, SolidWorks, or Rhinoceros may replicate joints exactly as they were planned digitally, assuring accuracy and precision without the minor changes that are frequent in handmade carpentry. Therefore, adopting CAD software simplifies the

manufacture of object joints that accurately resemble the original design. In figure 4 explain briefly about furniture joints using 3D printing.

The capacity to appraise a piece of furniture's load-bearing capacities determines how strong and long-lasting it is. Designers must understand the x-, y-, and z-axis load capacities for the joints they construct, as these are crucial for assessing the structure's general quality. Tenon mortise joints are advised for combined hardwood and plastic in furnishings, and 3D printing filament choices is critical for robustness and supporting loads performance. Proper selection, such as ABS filament, ensures longevity, particularly for minor furniture parts.

4.3 Finishing of 3D printing materials.

ABS filament is more efficient than PLA for manufacturing furniture joints. ABS is renowned for its resilience and adaptability under various environmental conditions, making it suitable for applications in the home as well as the outdoors. The furniture jointing method employs a sequential deposition strategy, starting at the bottom and working above. ABS filament is exceedingly affordable and widely used by 3D printing companies. FDM technique combines layers into each piece, necessitating careful machine settings to minimise seams on furniture linkages.

Three-dimensional printing filaments are generated from high-grade components, ensuring the high standards of each final product. Figure 4 shows the flow to produce finishing for furniture joint using 3D printing materials. FDM filaments available in a wide variety of hues. ABS is exceptionally robust, with high impact and durability against temperatures up to 100°C. Furthermore, ABS is a suggested alternative for practical prototypes or bigger objects that demand adequate room. The optimal machine settings for 3D printing are a print temperature of 245-265°C and a print speed of 30-50 mm/s. The printing process normally takes 4-5 hours for modest sizes, while larger sizes may take 1-2 days.

Designers review the print after it has been printed and finish the surface to ensure cleanliness and quality. This final step is removing filament supports from the product surface with pliers. Surface preparation is done manually, using sandpaper, putty filler, and primer. These approaches help to create a smooth, neat, and high-quality product surface.

Figure 4. Framework of furniture joints using 3D printing.

5 Conclusion

The implementation of 3D printing technology for furniture components is a new technique that has gained popularity in the contemporary furniture manufacturing industry. This process uses technology known as 3D printing to generate furniture parts. It significantly decreases the quantity of time required for putting together furniture components. Several furniture joints can be created simultaneously utilising 3D printing technology and pre-designed computer-generated models CAD. These variables furniture connectors were created utilising FDM technology, which is particularly suitable when ABS filament is utilised.

Additionally, contemporary furniture makes optimal use of plastic and wood elements. ABS filament is long-lasting and can withstand sunlight without fading or producing material issues. Tenon and mortise furniture joints outshine all other types of joints. These tenons make furniture assembly less complicated, improving accuracy and making it less challenging for customers to bring home the purchase.

On top of that, the advantages of employing three-dimensional printing for furniture joints include improved flexibility, the ability to create complex geometries that would be challenging to produce, and faster manufacturing operations. Designers should look closely at the users' needs by seeking insights into variation or changes that look appealing to potential users [10]. Obtaining high-quality designs becomes essential for furniture designers since

it demands an in-depth knowledge of the specifications for the 3D printing elements used, along with promoting that the expected furniture joints are strong enough for long-term use.

There are some recommendations for future research that can be carried out and improved based on the research that can be carried out and improved based on the research's experience throughout the research on furniture joints using 3D printing technology. Further reseacrh can be done focusing on the advantages of SLA technology and its use to produce suitable product and its can help further expand the use of 3D printing technology with the help of furniture desigers in the furniture industry in Malaysia.

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