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Research Article

The Application of 3D Printing Technology in Furniture Design

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With the gradual deepening of the combination of 3D printing technology and the furniture manufacturing industry, the production of 3D printed furniture has begun to transition from experimental single furniture production to small batch furniture production, which will profoundly affect the manufacturing mode change of the furniture manufacturing industry in the future. This paper conducts a detailed study on the complex molding links, product development links, parts production links, and product body forming links of 3D printing technology in the furniture manufacturing industry. The design and printing process can provide practical reference for the manufacture of furniture products.

1. Introduction

In the context of the development of high-tech technologies, 3D printing technology has emerged as the times evolve. 3D printing technology has the advantages of digital and intelligent development and can be customized for specific products. 3D printing technology is a transformative digital additive manufacturing technology that manufactures three-dimensional objects through layer-by-layer superposition of materials influence. In recent years, with the development of this technology becoming more and more advanced, 3D printing technology has been widely used in aviation, transportation, manufacturing, and other fields [1–5]. 3D printing technology plays an important role in promoting the transformation of our country's manufacturing industry from the "Made in China" model at the low end of the industrial chain to the "Made in China" model, assisting the overall development of the manufacturing industry to upgrade from the downstream processing and assembly links to the upstream design and development links [6–8]. While the 3D printing technology continues to progress, promoting the combination of technology and specific industries is the only way to promote its long-term development [9, 10].

While the impact of 3D printing technology on the manufacturing industry has been deepening, the competition in our country's furniture manufacturing industry has become increasingly fierce [11–13]. How to correctly grasp the future development direction is a problem that most furniture manufacturers continue to explore. At present, in the overall development of the furniture manufacturing industry, enterprises continue to integrate, the market is constantly subdivided, and the professional division of labor is more clear. However, there are still serious product homogeneity, slow update speed, waste of resources, and serious pollution in the manufacturing process of furniture. It is difficult to meet consumers' needs for originality, diversity, and environmental protection of furniture products. Furniture manufacturing enterprises have an increasingly strong demand for the improvement of furniture manufacturing process and furniture modeling structure [14–17]. In addition, the intelligent upgrading of furniture products in the context of the development of intelligent manufacturing is also a gradually improved field in the furniture manufacturing industry. In recent years, the development of intelligent furniture has accelerated significantly [18–20]. In this situation of rapid changes in the furniture manufacturing industry, the rapid prototyping

characteristics of 3D printing technology and the superiority of solving complex technological processes have brought it into constant contact with the furniture manufacturing industry, and in the process of furniture production, technology plays an important role in the development of the industry. Increasingly, the mass customization trend of 3D printed furniture is taking shape. From the perspective of the development of 3D printing technology and the background of the furniture manufacturing industry, the application of 3D printing technology in the furniture manufacturing industry is an inevitable product for the continuous interaction between technological progress and market demands [2, 21–23].

With the advancement of 3D printing technology and the continuous decline of material manufacturing costs, the development of its technology research and equipment manufacturing has accelerated significantly, but the corresponding industrial applications are still facing a huge bottleneck period. Some domestic researchers in the field of 3D printing technology do not know enough about the specific industry needs, and there is a lack of specific industry support for research on 3D printing technology and materials, while the insiders in the furniture manufacturing industry also have less contact with 3D printing technology and have little understanding of new technologies. The lack of broad awareness of application methods and advantages has seriously hindered the further promotion of 3D printing technology in the furniture manufacturing industry. In the urgent need to open the communication channel of technological progress and industrial market, the research purpose of this paper is to analyze the application status of 3D printing technology in the furniture manufacturing industry and provide solutions to problems in the furniture manufacturing process through the application research of 3D printing technology.

2. 3D Printing Technology

3D printing technology is accurate in physical replication, and combined with scanning technology, more accurate replication effects can be obtained; there are various materials, and 3D printing technology can be used to print different materials to meet the needs of various fields; the printing speed is fast, which is comparable to traditional manufacturing. Compared with the process, it saves a variety of complex processing and improves the efficiency; the manufacturing cost is low, and compared with the traditional machine tool processing, it saves the cost of manufacturing materials and transportation, which can effectively reduce the cost; the degree of personalization can meet a variety of demands, wide range of manufacture, and fast delivery time. The emergence of new technologies has both advantages and disadvantages. 3D printing technology consumes a lot, which is more than 10 times that of the traditional manufacturing processes. Therefore, under the current social background that promotes green energy, 3D printing needs to be transformed to reduce the existing energy consumption; the combination of 3D printing technology and biotechnology will bring certain security risks to the society. If there is no restriction, there will be contradictions that are inconsistent with the development of technology; the emergence of 3D printing technology provides convenience for lawbreakers, and it is easy to cause certain threats to public security; at the same time, there are certain restrictions on the selection of material varieties. Today, with the rapid development of computer technology, it is easy to copy and transfer relying on 3D technology; equipment is expensive, and if it is to be widely promoted and applied, certain difficulties will be faced.

2.1. Basic Concepts of 3D Printing. The 3D printing technology is also known as rapid prototyping technology or additive manufacturing technology. 3D printing is based on three-dimensional models, using materials such as wires, powders, and liquids that can be melted and bonded by heating and layer-by-layer superimposition. However, the modern society is increasingly pursuing personalized customization, which is consistent with the advantages of 3D printing, such as short production cycles, small batch production, and convenient product shape change, so it brings space for 3D printing development.

2.2. Basic Types of 3D Printing

(1) Fused deposition type: this printing type of FDM is the most basic and elementary type of 3D printing. It mainly uses plastic filaments (ABS, PLA, nylon, etc.) to be heated and melted by the nozzle of the printer, and then, the materials are layered layer by layer. Extruded onto the printing platform, according to the slicing of the 3D model, the multilayer accumulation is carried out and finally the shaping of the solid model is completed. The overall process is similar to squeezing toothpaste, so this technology does not have high requirements on the printing environment and consumables and is relatively easy to use and control. It is generally used as an introduction to 3D printing and teaching.

(2) Selective laser sintering type: this printing type of SLS mainly uses powder (metal, ceramic, wax powder, plastic powder, etc.) as the material and is performed by sintering and bonding. During processing, the powder is first preheated to a temperature slightly below its melting point and then flattened under the action of a leveling stick; the laser beam is selectively sintered according to the layered cross section information under computer control. The molding method has the characteristics of simple manufacturing process, high flexibility, wide range of material selection, low material price, low cost, high material utilization rate, and fast molding speed. According to the above characteristics, the SLS method is mainly used in the foundry industry and can be used directly to make quick stencils.

(3) Light-curing three-dimensional molding: this printing type of SLA mainly uses liquid photosensitive resin and is cured by light. Light-curing

molding is the most widely used due to its high degree of automation in the molding process, good surface quality of prototypes, high dimensional accuracy, and the ability to achieve relatively fine dimensional molding.

2.3. Research Status of 3D Printing Technology. The time from theoretical research to practical application of foreign 3D printing technology is relatively early, and most of the fields involved are at the forefront of the development of the times, from 3D printing automobiles, aerospace parts, high-end medical models, and new concept architectural design to manufacturing and other applications. The 3D printing technology has also achieved leapfrog development in the field of foreign art design. Art design-related industries have made various cross-border attempts combined with the advantages of 3D printing technology. 3D printed shoes, clothes, accessories, etc., have appeared in world-class fashion for many times shows and art exhibitions. The new era has brought new opportunities for the application of 3D printing technology in indoor home furnishing. Foreign developed countries have carried out a lot of research and application in indoor interface modeling design and interior decoration construction. For example, in interior decoration products, Nervous System, a design firm from the United States, used generative algorithms to create the latest lamps made of nylon material. Nervous System is shown in Figure 1.

When the Nervous System light is turned on, the light will penetrate the hollow and divergent branch and leaf shells and project into the indoor space, making people feel like they are in a dream forest. In terms of interior furniture products, Dutch designer Drik Vander Kooij has designed "Endless Flowing" furniture, as shown in Figure 2.

By observing the chair, people will not realize that the Endless Flowing" chair is made of 3D printing. This is because Kooij uses a unique technology in 3D printing: Kooij 3D prints the chair, unlike most 3D printed furniture. When printing, the printer only moves back and forth. Instead, he allows his 3D printer to print in multiple directions to create a unique appearance.

Domestic research on 3D printing technology started relatively late, and there is insufficient research on 3D printing technology methods. Although there are individual units or individuals with advanced awareness about the use of 3D printing technology in China, they are not in-depth enough. The traditional domestic products in the home furnishing industry are relatively simple in shape and function, and the actual products manufactured cannot meet the original intention perfectly due to the limitations of craftsmanship. The application of domestic 3D printing technology is mainly at the architectural level and design level, and some cutting-edge technologies still have to be imported from abroad. Since most companies do not have a strong awareness of the application of 3D printing technology, they have not dig deeper or are skeptical of it and still design and manufacture household products in accordance with traditional concepts and processes. Facing the reform of new production methods and the "re-industrialization

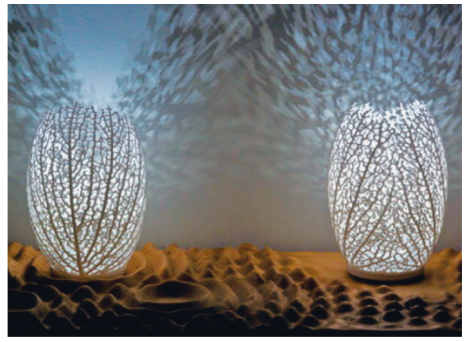

Figure 1: Vein lamps designed by Nervous System.

Figure 2: "Endless Flowing" furniture.

strategy" vigorously promoted by developed countries, the country attaches great importance to the R&D and industrialization of new digital manufacturing technologies such as 3D printing and intensifies personnel training, market cultivation, and application promotion. An example of the latest domestic experimental interior decoration works is the experimental villa of Shanghai Yingchuang Company's integrated printing of interior and exterior decoration and architecture, as shown in Figure 3.

With the development of the times, the new term "cross-border design" came into being. The innovative integration of craftsmanship is an important component of cross-border, and due to the requirements of new crafts and personalized design, 3D printing has become a tool that can concretize various personal tastes and materialized arts. The cooperation between interior decoration and 3D technology and convergence has become the inevitability of the times. The increasingly developed trend of 3D printing technology has greatly responded to people's claims of consumption and opened up a broader space for indoor home design. In the future, the application potential of 3D printing technology in indoor homes is huge, and it will better meet people's needs for personalized customization and modern smart home environment [15–17].

3. The Application of 3D Printing in Furniture Manufacturing

At present, the application scope of 3D printing technology in the furniture manufacturing industry is expanding, from

Figure 3: The world's tallest 3D printed building.

experimental single-piece furniture production to mold manufacturing, product development, parts production, and other manufacturing links. Its application mainly focuses on solving various complex problems such as shape complexity, material complexity, hierarchical complexity, and functional complexity in the production process. The 3D printing technology is closely related to the traditional furniture manufacturing process. The combination of new technology and traditional technology can cooperate to solve the problems of long R&D and production cycle and slow product update speed in the furniture manufacturing industry.

3.1. Application of 3D Printing Technology in Complex Furniture Molding. The application of 3D printing technology has promoted the current furniture manufacturing industry, which is firstly reflected in the simplification of the complex mold manufacturing process, which is used to solve the mold opening problem of some irregularly shaped furniture. In the prototype stage of furniture production such as upholstered furniture, metal furniture, and injection-molded furniture, some furniture or components need to be processed by plastic molding or metal casting and the furniture production is highly dependent on mold manufacturing.

Compared with traditional mold-opening methods, 3D printing technology is applied to the complex mold-making process of furniture products and its advantages are mainly reflected in the following aspects: first, it solves the rapid prototyping of complex shapes of molds and second, it saves the cost of furniture molding links. In the field of mold manufacturing, the application of 3D printing technology is also known as rapid mold manufacturing technology. This technology is used in conjunction with CNC machining centers, engraving machines, vacuum laminating machines, and other equipment to jointly provide rapid prototyping services for furniture molding. At present, the 3D printing technologies applied in the mold manufacturing process mainly include photocuring molding technology and selective laser sintering technology. The available printing materials include metal, plastic, ceramics, recycled paper, etc. When making molds with 3D printing technology, the shape of the mold is directly generated from computer graphics data, which can be adjusted at any time in the virtual model-making stage before the mold is printed.

3.2. The Application of 3D Printing Technology in the Research and Development of Furniture Products. At this stage, the application of 3D printing technology in the furniture manufacturing industry mainly focuses on the research and development of new furniture products and the printed furniture product prototypes are used for the appearance and structure verification of new products. The research and development stage of traditional furniture manufacturing usually requires multiple repeated communication processes such as product prototype design, mold making, and re-improving the prototype design. The one-time molding feature of 3D printing technology turns the repeated communication between furniture product design and mold production into direct printing of product prototypes, thereby simplifying the development process of furniture products as "furniture design-3D printing product prototypes-modifying product prototypes-reprinting and functional verification-final mold opening" process.

Specifically, the intervention of 3D printing technology is mainly to reduce the repeatability in the product development process through the following means:

(1) The performance of furniture products is pretested in the 3D model stage, and the process of determining the rationality of the design will be more concentrated in the stage of virtual model making and modification.

(2) The application of new technologies makes the design of furniture products take into account the satisfaction of product functions. The integrated molding of furniture products enables designers to obtain the prototype of furniture products more intuitively, better grasp the appearance and structure of furniture products, and improve the modeling accuracy. In the process of furniture design and modification, a variety of product prototypes can also be quickly printed, so that furniture product development can be upgraded from simple prototype trial production to conceptual model derivation, ergonomic analysis, visual analysis, form coordination and function testing, engineering comprehensive analysis of furniture products such as evaluation tests.

(3) We can concentrate on the product design department for mold making and small-scale trial production and reduce the time for docking with mold manufacturing enterprises, communication between company internal personnel, and product flow.

3.3. The Application of 3D Printing Technology in the Production of Furniture Parts. Since furniture products have high requirements on the structural strength and material adaptability of the connecting parts, the production of furniture parts mainly relies on standardized means to restrict the production of parts. In the assembly of traditional standardized connectors, the connectors are usually commissioned by furniture companies to produce parts manufacturers and complete the assembly in the furniture

assembly workshop. Although the standardized parts production process can meet the needs of various furniture connections, complex structural assembly processes are still required at the connections and furniture products exhibit obvious assembly characteristics. Therefore, furniture products are prone to wear and deformation of parts during use, and the service life is greatly affected by the firmness of the parts.

The application advantages of 3D printing technology in the production of furniture parts are as follows:

(1) The connectors are integrally formed by modular means, which reduces the use of screws and connecting hinges for furniture products, improves the degree of fit, and reduces the difficulty of parts production and assembly.

(2) In the mold-opening stage of traditional parts, a more concise mold shape is formed, so that the shape of the manufactured metal or plastic parts is more simplified, the structure is more reasonable, and it is beneficial to realize the simplified processing of complex structural parts.

(3) In addition to the initial process of applying 3D printing technology to furniture production, it can also exert its technical advantages in the process of secondary recycling of furniture, realize the processing of existing furniture incomplete parts, prolong the service life of furniture products, and obtain better quality products at a high environmental value.

3.4. The Application of 3D Printing Technology in the Molding of Furniture Main Body. In addition to the application in the auxiliary links of furniture production, the current industrial-grade 3D printers are mostly aimed at directly manufacturing molded products. The large-scale 3D printing equipment produced by some printer manufacturers specifically provides services for directly printing furniture products.

In the furniture main body forming process, the application advantages of 3D printing technology mainly include the following:

(1) 3D printing technology can reduce the time for auxiliary mold opening, parts production, assembly and splicing, and material consumption in furniture production, so that furniture products have the appearance characteristics of integral molding. 3D printing technology has successfully produced single furniture or small batch of furniture many times in the furniture manufacturing industry, and the products are mostly used for the manufacture and reproduction of high-end art furniture such as European-style or Chinese-style furniture.

(2) 3D printing technology can realize the one-time molding of the self-occlusal structure and cavity structure of the furniture. The printing of key parts of the furniture can remove the visual barriers of cumbersome mechanical parts and achieve a qualitative leap in functional innovation. The designer's consideration of the functionality of the work can be subtly realized through the modeling capabilities of computer modeling and 3D printing equipment. These structural features and plastic arts are usually difficult to achieve seamless assembly when they are made by cutting, molding, and other means.

(3) Manufacturers of 3D printing materials and equipment can conduct product research and development on nylon, wood-plastic, metal, resin, and other printing materials to obtain different textures of printing materials. These new printing materials realize the structural remodeling of traditional materials through the structural design of virtual three-dimensional models and provide new material choices for furniture production.

4. 3D Printing Furniture Product Model Practice

When the 3D printing equipment prints a single piece of furniture, its generalized manufacturing process consists of the following three parts: first, the acquisition of virtual 3D model data and format conversion are performed; second, the furniture is printed on the machine; finally, the post-processing after printing is performed.

4.1. Acquisition and Format Conversion of Virtual 3D Model Data. In the acquisition and format conversion of virtual 3D model data, there are mainly two steps as follows: first, acquisition of virtual 3D model data; second, model sorting and STL format conversion.

4.1.1. Acquisition of Virtual 3D Model Data. There are three main ways to obtain the virtual 3D data model of the furniture or parts to be printed: one is to establish 3D model data by means of traditional computer modeling software. The virtual 3D data modeling software that can be applied to 3D printing technology includes AutoCAD, Maya, 3DS MAX, Rhino3D, and other common commercial design software, and there are also relatively low-difficulty design software packages such as Blender, Sketch Up, and Tinkercad. At present, this method is the more commonly used modeling method. Through short-term learning, we can quickly grasp the modeling requirements of 3D printing furniture; the second is to establish 3D model data through parametric design software. Among the commonly used parametric design software, the mainstream application software is Pro/Engineer, UGNX, CATIA, and Solidworks. The modeling method of parametric design software can enable furniture products to establish various constraint relationships based on the parametric models, realize more intelligent programming design, and obtain the systematic and growing model effects so that furniture products can be standardized according to user requirements. With rapid customized modeling on the basis of products, this way of

building 3D data models is more in line with digital modeling thinking, so it can better utilize the advantages of 3D printing technology; the third is to obtain 3D models of existing furniture by using scanners and tactile devices After the furniture data is scanned by the 3D scanner, it needs to be converted into a triangular mesh model by a software. The advantage of this method is that it can realize the function of quickly copying the existing furniture products.

4.1.2. Model Sorting and STL Format Conversion. After acquiring the virtual 3D model data, it is necessary to scale and repair the model to adapt it to the size, model, and resolution of the printer used and then convert the data format of the furniture model after adjustment. After these virtual 3D models obtained by modeling or scanning are established, they need to be uniformly converted into a file format that can be read by the driver software of the 3D printer, usually into a printable multilateral network file, that is, a file in STL format. STL is one of the commonly used file formats for 3D printing. Specifically, small triangular patches in a large number of spaces are used to approximate the solid model, and the solid object is cut into digital cross sections or layers by software and divided into equal thicknesses along the Z axis. Slicing creates a two-dimensional image, which is transmitted to the machine according to the image information. Different materials are bonded and stacked layer by layer to form a three-dimensional entity, and then, the necessary code that can control the 3D printer hardware to construct the object is generated, which is stored in the database for future modification and use.

4.2. Printing Furniture on the Machine. After completing the processing of the 3D data model of the virtual space, the printing enters the specific manufacturing stage. When printing furniture, you need to choose a 3D printer that meets dimensional accuracy and structural strength to maintain continuous print jobs. The process steps are as follows.

4.2.1. Performing Layering and Support Settings. At present, the professional layering software mainly includes SLICER and SFACT. After the layering is completed, the generated GCODE file is transferred to the 3D printer. The thickness of each thin layer can be appropriately adjusted according to the type of printer and printing accuracy, generally in between tens to hundreds of microns. It is worth noting that the reasonable and accurate handling of complex models largely determines the success or failure of the printed product. The processed model needs to ensure that there are no overlapping triangles, and if there are overlaps and holes, the transcribed 3D model may break or the file may not be printed after transfer to the printer. For the problems of material consumption and printing time in large-volume solid virtual models, under the premise of ensuring the structural strength, the structure can be simplified and hollowed out to form a hollow shell-like object. This process needs to consider the following aspects: Firstly, the minimum wall thickness of the printing material needs to be met. Secondly, if it is a liquid printer, it is necessary to leave a minimum overflow hole when printing the model and finally set the width and height requirements of convex or concave detailed structures (such as yin and yang engraved characters) question.

4.2.2. Importing the Printer Program to Complete Printing. After finishing the previous link, the generated GCODE file is sent to the 3D printer for identification and printing, thus completing the acquisition and format conversion of the virtual 3D model data. In specific applications, printers of different molding methods and models are slightly different in receiving print data, which is embodied in differences in transmission speed, storage, and instruction set.

4.3. Postprocessing after Printing. After the main body of 3D printing furniture is completed, the key application difficulty is the postprocessing link. Like the furniture produced by the standardized production line, after the main body printing process of the furniture is completed, a series of postprocessing procedures such as grinding, polishing, and coloring of the furniture can be performed according to the requirements for the fineness of the molding surface and we can complete inspection and packaging of furniture products and finally complete furniture production.

At present, the postprocessing methods that can be used for 3D printing furniture mainly include the following: plastic, nylon, glass, and other parts. These are postprocessed by component splicing, sandpaper grinding, manual polishing, coloring, and steam smoothing; metal parts are processed by electroplating, oxidation, chemical conversion coating treatment, thermal processing, and other means for posttreatment. From the perspective of the entire production process, according to the structural characteristics and actual use of the product, various manufacturing modes such as printing first, processing after printing, processing while printing, and no processing after printing can be formed to complete large-scale, high-density, and high-quality products in a flexible and efficient way manufacturing of precision, complex products.

5. Conclusion

With the gradual deepening of the combination of 3D printing technology and the furniture manufacturing industry, the production of 3D printed furniture has begun to transition from experimental single furniture production to small batch furniture production, which will profoundly affect the manufacturing mode change of the furniture manufacturing industry in the future. This paper conducts a detailed study on the complex molding links, product development links, parts production links, and product main body forming links of 3D printing technology in the furniture manufacturing industry, as well as its general characteristics when using 3D printing equipment to print furniture products. The molding process, in the actual application process, needs to choose the appropriate printing

method according to the furniture production requirements and the characteristics of the printing equipment.

The application of 3D printing technology in the furniture manufacturing industry is a newborn calf compared to the current relatively mature furniture production technology. With the gradual expansion of the application depth in recent years, the state's support for this technology has also been unprecedentedly high. However, it is undeniable that due to the few examples of technology industry applications, the authors are still lacking in the ability to write papers and the research may be biased and not in-depth, such as statistical sorting of 3D printing technology data and specific cases in the argument. Analysis is not thorough enough. These reasons lead to the data legacy and some deficiencies in the research in this paper. These unresolved problems are also the key to the future development and application of 3D printing technology in the field of furniture manufacturing.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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