Integrating 3D Printing Technology into Wooden Furniture Upcycling

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Abstract. This study aims to explore the potential of utilizing 3D printing technology for repurposing discarded wooden furniture. Our study combines literature review and case analysis to identify effective methods and implementation steps for integrating 3D printing into the upcycling processes of furniture. Our findings provide valuable insights into the practical application of 3D printing technology and offer a clear roadmap for sustainable furniture revitalization. This work also contributes to reducing waste, enhancing resource efficiency, and promoting sustainability in the furniture industry. Ultimately, our research underscores the innovative potential of 3D printing technology in this context.

Keywords: 3D printing technology, wooden furniture, upcycling.

1 Introduction

According to the World Furniture Outlook 2018 published by the CSIL, in 2017, global furniture production reached USD 420 billion, and China alone accounted for nearly 40% of the global output [1]. As of 2021, China has become the world's largest furniture manufacturer. Huajing Industry Research Institute shows that wooden furniture together accounts for nearly 33.3% of the furniture manufactured in China.

The annual amount of municipal waste produced in China is around 6 billion tons [2]. Roughly estimated, about 60 million tons of this is waste wood material, which is equivalent to a volume of 85 million cubic meters. The main source of waste wood is industrial or domestic waste wood, with a large proportion coming from discarded wooden furniture [3]. For a long time, China has been recycling less waste furniture materials, mostly burning or landfilling them together with other waste, which not only has a certain impact on the ecological environment and human health but also causes a serious waste of natural resources [4]. Thus, used-furniture recycling can not only alleviate the shortage of wood resources and serious waste effective, but also promote the sustainable development of the furniture industry and achieve a win-win situation between environmental protection and economic development [5], which is important to stimulate the development of a sustainable.

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According to the World Commission on Environment and Development, sustainability is "a form of development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]. Upcycling is frequently thought of as a process that converts waste materials into something of higher quality/value in a second life. Reference [7] define upcycling as a process of "reusing discarded items or materials to create a product of higher quality or value than the original". In recent years, the term "upcycling" has become widely popular and seems to have become a new design trend. Some scholars believe that upcycling at the level of products and items is considered one of the most sustainable solutions. This is because upcycling usually requires minimal inputs and can reduce the demand for new products [8].

Additive manufacturing (AM), also known as 3D printing, allows objects to be fabricated layer by layer, enabling three-dimensional objects to be 'printed' on demand [9]. AM has been recognized as an efficient and sustainable technology in modern manufacturing having the potential to provide a series of sustainability features [10]. In recent years, an increasing number of scholars have begun to pay attention to additive manufacturing technology, and some researchers in references [10, 11] believe that AM has potential benefits for sustainability and is considered as a key manufacturing technology in the sustainable society of the future.

The aim of this study is to investigate the potential and effectiveness of employing 3D printing technology for repurposing wooden furniture. This forward-thinking and eco-friendly approach strives to bring renewed vitality to outdated wooden furnishings while integrating the cutting-edge capabilities of 3D printing.

2 Literature Review

2.1 Upcycling of Wooden Furniture

Based on the summarization of existing recycling technology and methods, reference [12] analyzed the diversified innovation and reuse of discarded wooden furniture from various aspects in combination with the aesthetics and needs of people nowadays, aiming at revealing the hidden value of waste materials. Their research provides new ideas for the recycling of waste wooden furniture and creates added value for used furniture. A study from reference [13] proposes a systems approach for scaling up global upcycling, causal loop diagram (CLD) [14] is developed to illustrate key system variables and their dynamic interactions in the upcycling system. A preliminary framework is introduced to address upcycling from an object-oriented perspective. A bidirectional multi-level taxonomy is presented to address notions of design, manufacturing, sustainability, circularity and respect for the environment. Another study by reference [15] explores how designs are sustainably approached in the commercial context of young product design companies in the UK and propose a set of practical guidance through design outcomes to help design students deal with environmental issues via design and waste material reuse. This work may inspire designers and students to reconsider the use of waste materials in their practice, rediscover the beauty and usefulness of these materials, to create attractive commercial

products, raise awareness of material reuse, and help to make a net positive environmental impact through a structured design process using the guidelines.

Reference [16] presents a conceptual framework for the methodology of the benefits of the upcycling process in recreating and reinventing new products based on user feedback. They believe that exploration and experimentation of the usage and the density of the waste plastic material can be transformed into a new furniture application design that can offer new potential materials and images. There are two main approaches to furniture recycling and reuse: aesthetic refinishing design and functional modification design [17]. The specific implementation processes include the methods of refurbishment, addition and subtraction, and reassembly. The design methods for recycling and reusing discarded furniture can be categorized into renovation design, disassembly design, component combination design, and component design. According to reference [18] and other researchers, commonly employed methods for upgrading and remanufacturing wooden old furniture include value-added designs within the context of reuse-oriented recycling, value-added designs within the context of recycling-oriented reuse, value-added designs within the context of regeneration-oriented reuse, and value-added designs within the context of artistic and DIY utilization.

Sustainable redesign of furniture products encompasses three aspects: aesthetic redesign, structural redesign, and functional redesign. The disassembly and reuse of furniture, considered both energy recovery and a form of redesign, plays a crucial role in this process. According to reference [19], the reuse of discarded solid wood furniture can be categorized into direct reuse and indirect reuse. In China, as stipulated by GB/T 22529-2008 "Management Specification for the Recycling and Reuse of Waste Wood Materials," discarded wooden furniture can be reused through refurbishment, repair, or renovation methods [17]. Direct reuse involves the assessment of discarded furniture, with pure solid wood furniture that remains usable being subject to refurbishment and further processing for entry into the second-hand furniture or refurbished furniture market. Indirect reuse encompasses whole reuse, partial reuse, recycling, and thermal utilization.

2.2 3D Printing Technology in Furniture Industry

According to reference [20], the positive results of using additive manufacturing demonstrate that, despite some minor obstacles and problems in connecting different production processes, additive manufacturing will play an important role in the future design and production of furniture. Rapid prototyping, single-piece production, free-form design, and the use of bio-based materials and their recycling capabilities are the most significant advantages of 3D printing.

Reference [21] provide solutions to problems in the furniture manufacturing process by investigating the application of 3D printing technology in the furniture manufacturing industry in terms of complex molding links, product development links, parts production links and product main body forming links, as well as the general characteristics of furniture products when they are printed using 3D printing equipment. In reference [22] research, they designed a 3D printed connector to be used for joining

three chair components, namely the leg and two stretchers made of larch wood, and they 3D printed this connector using AM with fused filament fabrication (FFF) technology. They believe that the use of 3D printing technology in the furniture industry is feasible and beneficial in the long run, particularly for chairs with complex joints involving more stretchers and different jointing angles. Three-dimensional printed connectors are also advantageous for product design, as they allow for the combination of colors and structures.

To find a simple shaped connector that could be used to manufacture a chair and withstand the load requirements of a standard chair. Reference [23] developed, tested and numerically analyzed 3D-printed connectors to replace the typical L-shaped connectors in chair construction. Various connectors were designed and manufactured using an FDM 3D printer and acrylonitrile butadiene styrene (ABS) to find a simple-shaped connector that could be used to build chairs and withstand standard chair loading requirements. They tested the strength and stiffness of the joints and compared them to traditional beech mortise-and-tenon joints. The experimental results revealed that joints with 3D-printed connectors were weaker than traditional wooden mortise-and-tenon joints of comparable dimensions. The chair assembled with 3D-printed connectors may be able to withstand seating loads, but the connectors must be optimized and reinforced to withstand standard loads.

3 Methods

The literature review method and the case study method were used in this study. A literature review is a more or less systematic method of collecting and synthesizing previous research [24, 25]. As a research method, an effective and well-conducted review establishes a firm foundation for advancing knowledge and facilitating theory development [26]. The case study method is a type of field research technique. Field studies are investigations of phenomena as they occur without the investigators intervening significantly [27]. According to reference [28], a case study is a detailed analysis of a single case that assumes "one can properly acquire knowledge of the phenomenon from intensive exploration of a single case" (p. 75). The case study aims to arrive at a comprehensive understanding of the event under study while also developing more general theoretical statements about regularities in the observed phenomena.

3.1 Case of 3D Printing Technology in Furniture Design

The 3D printed gradient furniture collection is Philipp Aduatz's latest project in the field of 3D concrete printing. It is a new and innovative fabrication technology that allows printing of very large and complex structures in construction and design in a very short period. The advantages are not only from ecological and economic reasons, no extensive mould production is necessary, but also from new aesthetic qualities.

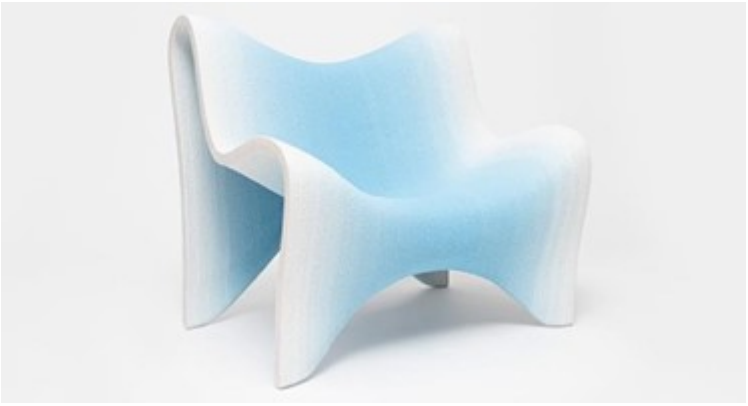

Fig. 1. Gradient Fauteuil
(Source: https://www.philippaduatz.com/portfolio-item/gradient-fauteuil/)

Designer Jon Christie has been exploring ways to combine traditional furniture making with 3D printing technology. Using hybrid 3D printing technology, he has designed and produced a set of tables and chairs that blend authentic craftsmanship with modernist design. The pieces created through the use of 3D printing are not only flexible and stylish but also affordable. The set combines walnut wood and polyamide plastic to create a striking contrast in materials and colors.

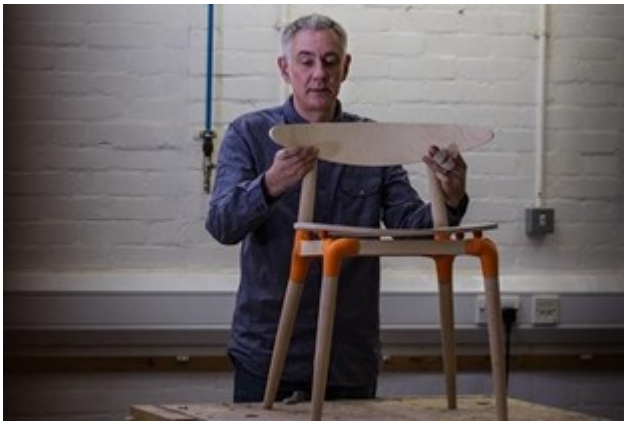

Fig. 2. 3D Printed and Walnut Table and Chairs
(Source: https://i.materialise.com/blog/en/exploring-3d-printing-in-furniture-design/)

The Rio Collection is a collection of furniture developed and designed by Morgan Furniture Company in collaboration with INTEGRATE Studios. The aim is to explore the combination of today's craftsmanship with the craftsmanship of tomorrow. The collection offers a series of dining/meeting chairs with backrest options in timber,

upholstery or a 3D-printed component. 3D printing construction uses a mathematical algorithm to create an intricate sculptural backrest and arm. Printed in polyamide.

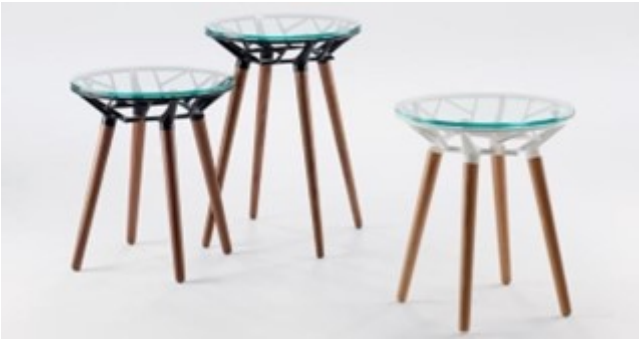

Fig. 3. Rio Side Table
(Source: https://www.morganfurniture.co.uk/collection/rio/)

BigRep is a German company specializing in FDM 3D printers with large print volumes and precision. Ocke series furniture was designed by Beatrice Müller, the company's 3D designer. The 3D-printed furniture set consists of chairs and sofas, all of which can be printed in one piece on this machine without the use of any support material. As Müller explains, 3D printing gives designers more design freedom to create new and interesting concept ideas.

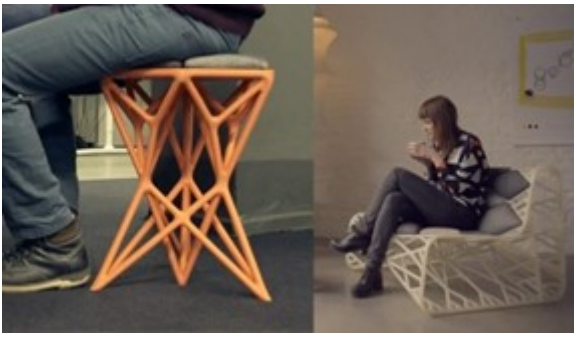

Fig. 4. BigRep's Ocke Series Furniture
(Source: https://bigrep.com/ /)

3.2 Cases of Furniture Upcycling

In Indonesia, there is a company called "All from boat", whose furniture products are made from wood restored and derived from old boats such as mahogany and Tectona. They use scrap wood from old ships as a raw material for making furniture. The timbers used in the production of furniture are old solid timbers, but they have not outlived their usefulness and they still have great properties. These woods can be used to produce almost all furniture. As shown in Figure 5, these pieces of furniture are not only

environmentally friendly, but they also have a colored decorative surface that is unique to marine timber, and each piece of furniture is unique in design shape and color, making it difficult to imitate or replicate.

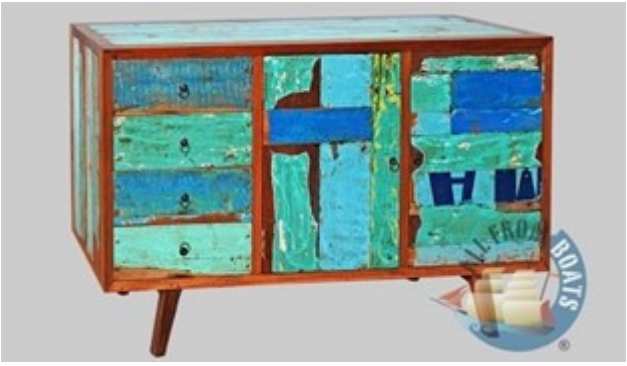

Fig. 5. Sideboard Made of Boat Wood
(Source: https://www.allfromboats.com)

This design project by Laquercia21 utilized recycled second-hand furniture using wooden floors and even discarded timber from construction sites to design and manufacture a range of furniture products. The structure of the Madie Alte Dispense sideboard is made of stable materials: plywood, marine plywood, MDF (medium-density fiberboard) or blockboard wood, which are suitable for a lacquered finish or a resin covering. The choice of colors is completely free, all the customer has to do is find their preferred shade and provide the RAL code.

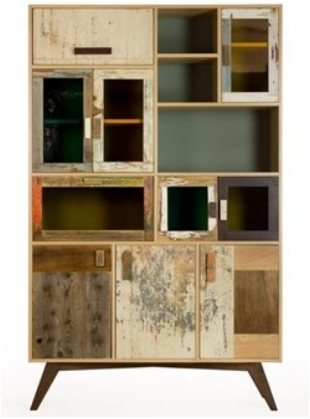

Fig. 6. Sideboard Made of B Waste Wood
(Source: https://laquercia21.it/portfolio/dispense/)

Rag Chair is layered from the contents of 15 bags of rags, each piece is unique, simple and brutal, but with a special aesthetic and practicality. What's special about these

chairs is that users can choose to recycle their unwanted clothes and incorporate them into the design. The Rag Chair not only helps users solve the struggle of where to go with their used clothes but also preserves the memories of those clothes stored.

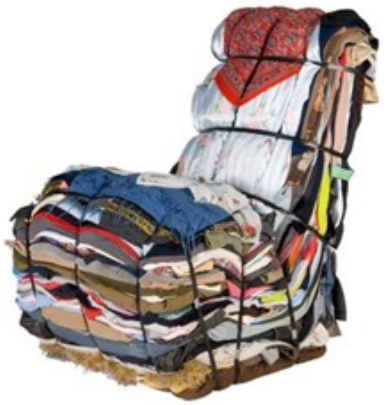

Fig. 7. Rag Chair
(Source: https://shop.droog.com/product/rag-chair/)

4 Findings

This study comprehensively investigates the current situation of furniture upcycling and the application of 3D printing technology in furniture design through a combination of literature review and case study. Basic methods and strategies for applying 3D printing technology to the practice of upcycling wooden furniture are proposed. The strategies are as follows:

1. Customized Connectors and Components: Through 3D printing technology, it is possible to create specialized connectors of specific dimensions and designs to meet the unique requirements of customers and the particular design needs of discarded furniture. This approach allows for highly personalized and adaptable upgrades and transformations of discarded furniture while enhancing its functionality and utility. 3D printing can also be employed to manufacture replacement parts for damaged furniture, which can be seamlessly integrated into discarded furniture, facilitating the creation of new furniture configurations. For instance, missing screws, nuts, or support blocks can be replaced, thereby extending the lifespan of the furniture without the need for complete disposal.
2. Complex Structural Design: 3D printing technology enables the realization of intricate geometric structures and designs, which prove invaluable in enhancing the aesthetics and functionality of furniture during the upgrading and remanufacturing process. Exquisite decorative and connecting components or complex joinery structures can be crafted, for instance.

3. Personalized Customization: 3D printing allows for personalized customization according to specific customer preferences and requirements. Customers can select the appearance, textures, and decorations of personalized furniture, tailor the ergonomic dimensions to suit their individual needs, incorporate personalized logos and markings, and choose customized materials to meet their unique aesthetic and size preferences.
4. Material Innovation: 3D printing technology enables the use of multiple materials, or even a variety of new materials, including sustainable materials and composites, in the same upcycling process of used furniture, thus improving the performance, sustainability and aesthetics of the furniture. This material innovation contributes to transforming discarded furniture into products of higher value and sustainability. For example, 3D printing technology can combine metal components with wooden ones, increasing the furniture's strength and stability.
5. Rapid Prototyping: Designers can utilize 3D printing technology to create rapid prototypes for upgraded and remanufactured furniture, allowing them to test and validate new design concepts and thereby reduce errors and costs before the remanufacturing process.
6. Refinement and Restoration: 3D printing can be employed for the refinement and restoration of discarded furniture, including the addition of decorative elements, the repair of surface imperfections, and the application of coatings. This helps improve the appearance and aesthetics of discarded furniture.

5 Conclusion

This research aims to explore the integration of 3D printing technology into the upcycling practice of discarded wooden furniture, addressing the challenges faced by the furniture industry in terms of sustainability. In the introduction, within the context of the furniture industry and the issue of furniture waste, it was recognized that the problem of waste generated in the furniture production process has become increasingly severe, placing significant pressure on the environment. Against this backdrop, the concepts of sustainable design and upcycling have gained paramount importance, and additive manufacturing, specifically 3D printing, as an innovative technology, has opened up novel possibilities for furniture upcycling. This study employed a combination of literature review and case study methods to conduct an in-depth investigation into the methods of upgrading and remanufacturing wooden furniture and the application of 3D printing in furniture design. Through the analysis of cases related to furniture product upgrading and remanufacturing and 3D-printed furniture, we propose specific methods for integrating 3D printing technology into the upgrading and remanufacturing of discarded furniture.

However, this research has certain limitations that may impact its broader applicability. Firstly, the current state of 3D printing technology still faces certain constraints, including limitations in material selection, printing speed, and cost factors. Consequently, practical applications may encounter challenges related to technological feasibility and cost-effectiveness. Secondly, this study solely focused on the application

of 3D printing technology in furniture upgrading and remanufacturing, whereas the field of furniture design and manufacturing encompasses a broader spectrum.

In summary, despite achieving positive outcomes in the integration of 3D printing technology into the practice of upgrading and remanufacturing discarded wooden furniture, this study has encountered certain technological limitations. In the future, we need to further validate these methods and steps through extensive design practice. Moreover, more factors such as industry needs, market requirements and consumer needs need to be considered, which will help the furniture industry to develop more comprehensively and sustainably. Through the exploration conducted in this study, we have presented novel ideas and methodologies for the upgrading and remanufacturing of discarded furniture in China, with the hope of making a meaningful contribution to the promotion of sustainability within the furniture industry.

Paper Contribution to Related Field of Study. This research, by delving into the issues of sustainability within the furniture industry, presents an innovative approach to applying 3D printing technology to the upgrading and remanufacturing of discarded wooden furniture. Through theoretical exploration and practical investigation, we have confirmed the feasibility and value of this approach. The research findings underscore that 3D printing technology presents an innovative avenue for the upgrading and remanufacturing of discarded wooden furniture. We discover that through the customization of components, the utilization of novel materials, and the realization of personalized design, discarded furniture can experience a renaissance, reducing waste generation, enhancing resource utilization efficiency, and advancing a more sustainable approach to furniture manufacturing. In conclusion, this study emphasizes the potential of 3D printing technology in fostering sustainability within the furniture industry and advocates for further exploration, both in practical applications and research endeavors, to propel the upcycling of discarded wooden furniture, thereby contributing to environmental and societal sustainability. Through the practical exploration of this study, we provide new ideas and methods for upgrading and recreating discarded furniture in China and hope to make a meaningful contribution to promoting the sustainable development of the furniture industry.

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