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# INTEGRATING 3D PRINTING TECHNOLOGY INTO FURNITURE UPCYCLING COURSE: AN EXPLORATION OF TEACHING PRACTICES IN CHINA

Liu Senlin[1*], Sharin Mokhtar[2], Natrina Mariane P. Toyong [3]

[1] College of Creative Art, Universiti Teknologi MARA, Malaysia
Email: 547848859@qq.com
[2] College of Creative Art, Universiti Teknologi MARA, Malaysia
Email: sharin2066@uitm.edu.my
[3] College of Creative Art, Universiti Teknologi MARA, Malaysia
Email: natrinatoy@uitm.edu.my
[*] Corresponding Author

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**Abstract:**

This research examines the integration of 3D printing technology in practical courses focused on upcycling wooden furniture. By utilizing literature reviews and case study methods, it evaluates five practical cases of upcycling wooden furniture in order to emphasize considerations for incorporating 3D printing technology into teaching practices. The objective of this study is to identify significant issues and challenges in this process, providing valuable insights for educators and practitioners involved in upcycling wooden furniture through the application of 3D printing technology.

**Keywords:**

3D Printing Technology, Teaching Practice, Upcycling, Wooden Furniture

## Introduction

The Chinese furniture industry is the largest in the world. It is also a top producer, consumer, and exporter of furniture. The industry is projected to grow at an annual rate of 11.57% between

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2022-2026(Klooster., 2022). According to the National Bureau of Statistics, the combined revenue of furniture manufacturers increased 13.5% in 2021 to RMB800.46 billion(HKTDC, 2022).

However, Resource shortages and significant waste are hindering the furniture industry's sustainable development, and it is imperative to address this issue urgently. Moreover, with the increase in living standards, the pace of replacing furniture has accelerated as well(Mao & Wu, 2016). The typical life span of many furniture items ranges from 5 to 8 years. However, there has been an accelerated rate of obsolescence in furniture products, leading to a rise in the disposal of used wooden furniture. Historically, China has exhibited low levels of recycling for waste furniture materials, often resorting to methods such as incineration or landfilling alongside other waste materials. This practice not only poses environmental and health risks but also results in significant wastage of natural resources(Chen et al., 2019).

In China, the comprehensive utilization rate of wood is reported at 65%, significantly lower than the exceeding 80% rates observed in developed nations. This disparity highlights the potential for significant adverse impacts on human health and the environment stemming from inadequate wood management practices. Consequently, the adoption of used furniture recycling emerges as a viable approach to not only address the scarcity of wood resources and associated waste issues but also to foster sustainable development within the furniture industry(Eisenlauer et al., 2018). This endeavor aims to establish a harmonious balance between environmental preservation and economic advancement, thus contributing to the cultivation of a sustainable furniture industry in China(Lv et al., 2023).

The state has promulgated a series of laws and regulations to regulate and guide the corresponding enterprises and consumers to recycle and reuse waste wood materials, so as to build a preliminary recycling system for waste wood materials(ZHANG, 2021). Nonetheless, despite the substantial annual accumulation of waste furniture in China surpassing that of traditional wood materials, and the significant regional disparities in waste furniture disposal methods, the country has yet to establish an effective and mature recycling system for used furniture on a nationwide scale.

The swift progress of both the economy and society has placed substantial strain on environmental integrity and finite resource availability. The global advocacy for the remanufacturing sector represents an avenue for achieving a mutually beneficial outcome, wherein resource conservation and environmental preservation are prioritized, thereby fostering sustainability(Lv et al., 2021). As highlighted in an official report by the Chinese government, there is a pressing need to enhance overall resource utilization efficiency, expedite the establishment of waste material recycling systems, and advance the sustainable development of the ecological environment. Concurrently, the rapid advancements in science and technology have significantly bolstered the reliability and durability of products. However, this has been accompanied by a reduction in product lifespan, falling short of their potential service duration.

The integration of 3D printing technology in the educational practice of upcycling wooden furniture presents a number of concerns and challenges. Firstly, some of the problems in this topic include the compatibility of 3D printing technology with traditional woodworking techniques, the adaptability of material selection, and the degree of students' acceptance and

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mastery of the new technology. These issues not only affect the effectiveness of teaching and learning, but also place higher demands on practical practice.

Some of the main challenges or problems faced by previous studies in this area focus on several aspects: first, the effectiveness of 3D printing technology in wood furniture reconstruction has not been fully verified, second, the existing teaching methods are difficult to effectively combine traditional crafts with emerging technologies, and third, there is a lack of systematic case studies to support theoretical explorations. These challenges make how to effectively introduce and apply 3D printing technology in the curriculum a pressing issue.

The scope of this study consists of evaluating five real-life examples of upcycling wooden furniture through a literature review and case study approach. The research focuses on analysing the performance of 3D printing technology in these real-world applications, identifying key issues and challenges in the integration process, and providing valuable insights for educators and practitioners. Through in-depth analyses of these cases, this study aims to provide theoretical and practical support for the integration of 3D printing technology into the teaching and learning practice of wood furniture reclamation.

The aim of this study is to explore how 3D printing technology can be utilised in a university furniture design course to enable the upcycling of used furniture. The research aims to investigate the feasibility and effectiveness of employing 3D printing techniques to breathe new life into old furniture, contributing to a sustainable and innovative approach to both furniture restoration and design education.

## Literature Review

The literature review will discuss the following six points, which are sustainable design, upcycling, Additive manufacturing, Upcycling of Wooden Furniture, Upcycling in Furniture Design in Universities, 3D Printing Technology in Furniture Industry.

### *Sustainable Design*

The notion of design for sustainability originates from the broader framework of sustainable development, which represents both a theoretical contemplation of the interconnectedness between economic progress, environmental preservation, societal well-being, and other facets, as well as an ongoing design endeavor aimed at fostering adaptation and evolution. As articulated by the World Commission on Environment and Development, sustainability entails "a mode of development that fulfills the current needs while safeguarding the capacity of future generations to fulfill their own needs"(Rakhimova, 2017). Fundamentally, any educational, practical, or research endeavors within the realm of design that adhere to the principles of sustainable development are classified under the umbrella of sustainable design(Vezzoli et al., 2017). Sustainable design is a design that takes into account the interests of the natural environment(Galeeva et al., 2018). Sustainability has emerged as the pathway forward, underscoring the importance of adeptly managing the generation and disposal of municipal solid waste to enhance our living environment.

### *Upcycling*

The term "upcycling" was introduced by William McDonough and Michael Braungart, pioneers of the circular economy movement and proponents of the "cradle to cradle" concept. Their book "The Upcycle" outlines the principles of upcycling, challenging the conventional

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notion that recycling is the optimal method for managing used products. Instead, they advocate for remanufacturing, whereby used products are transformed into new items of greater value, rather than being recycled into materials or energy(McDonough & Braungart, 2013).

Upcycling is defined as a process to "reuse discarded objects or materials in such a way as to create a product of higher quality or value than the original" (Bridgens et al., 2018). Since upcycled products are created by repurposing old or discarded materials, they often undergo a transformation into something functional and aesthetically appealing(Ali et al., 2013; Teli et al., 2014), recently, several emerging companies have been selling upcycled products as a means for future growth in the context of sustainable production or design(McDonough & Braungart, 2002). Because of these benefits, lots of interest in upcycled fashion has emerged from academia and the industry in recent years (Coppola et al., 2021; Peschel & Aschemann-Witzel, 2020; Yu & Lee, 2019).

As a sustainable solution, upcycling continues to attract the attention of scholars, the industry, and environmentally conscious individuals (Coppola et al., 2021; Peschel & Aschemann-Witzel, 2020; Yu & Lee, 2019). Upcycled refers to a process in which used materials are converted into new items of higher value and quality in their next lifecycle (Coppola et al., 2021; Peschel & Aschemann-Witzel, 2020; Sung, 2015; Yu & Lee, 2019). The global upcycling market is valued at $150 million, with notable growth observed particularly in the United States. For instance, the number of products labeled as "upcycled" surged to 30,000 in 2011, marking a remarkable year-over-year increase of 275%. By 2013, this figure soared to 263,685, reflecting an additional surge of 879%(Xu & Gu, 2015).

***Additive Manufacturing***

Additive manufacturing (AM), also known as 3D printing, it's defined as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining"(Astm, 2010). Additive manufacturing(AM) has been acknowledged as an effective and sustainable technology in contemporary manufacturing, with the capacity to offer a range of sustainability attributes(Ford & Despeisse, 2016). In recent years, an increasing number of scholars have begun to pay attention to additive manufacturing technology, and some researchers (Chen et al., 2015; Ford & Despeisse, 2016) believe that Additive Manufacturing(AM) is viewed as a pivotal manufacturing technology in shaping the sustainable society of tomorrow, owing to its potential advantages for sustainability(Huang et al., 2013). Additive manufacturing mimics biological processes by creating products layer-by-layer. It is inherently less wasteful than traditional subtractive methods of production and holds the potential to decouple social and economic value creation from the environmental impact of business activities.

***Upcycling of Wooden Furniture***

In recent times, upcycling design has emerged as a potential solution to address the issues of waste management and sustainable consumption. The concept of upcycling design is gaining momentum as an environmental consciousness movement, which is not just limited to individuals but is being embraced at the state level as well.

Ahn and Lee (2018) conducted a case analysis to determine the importance of material life experience in the upcycling design process. The study resulted in the development of a sustainable 'Iterative Upcycling Design Process Model', which is a conceptual model of a

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continuous material life cycle in the upcycling product designing system. Their study explores the second life cycle of upcycled products, focusing on the material life experience during the upcycling design process in Korea. It suggests a design process that takes into account the material life cycle, leading to sustainable upcycling design. They suggest that in the early stages of the upcycling design process, the focus should be on materials and their recyclability.

Buck and Lee (2020) researched sustainable design approaches in young product design companies in the UK, and proposed a practical guidance to help design students deal with environmental issues by reusing waste materials in their designs. This research aims to inspire designers and students to reconsider the use of waste materials, and create attractive commercial products that raise awareness of material reuse and make a positive environmental impact. The proposed guidelines provide a structured design process to achieve these goals.

Ahmad et al. (2020) have proposed a conceptual framework for the methodology of upcycling process. The framework aims to explore and experiment with the use and density of waste plastic material to create new furniture designs based on user feedback. The researchers believe that this approach can offer new potential materials and images, thereby recreating and reinventing new products.

***Upcycling in Furniture Design in Universities***

Ismail (2022)'s study aims to explore the possibility of recycling abandoned furniture found at the University of Jordan and transforming it into a new aesthetic language that can produce unique and functional pieces of furniture. The new formulation should not only be visually appealing but also fulfill the needs of the individuals who interact with it.

The author conducted a descriptive analytical study on five purposive samples. The study led to several conclusions, the most significant of which was that the student successfully redesigned old furniture into modern versions in terms of form and content. The student achieved this by merging old materials with new materials, which resulted in a new version that was both functional and aesthetically pleasing. Furthermore, the study stimulated and provoked the student's mind by laying the foundation for reformulating the individual's relationship with the environment. This was achieved by raising awareness of the importance of recycling and visually encouraging the individual to appreciate the artistic creations resulting from recycling.

Through reading the relevant literature we found that there are relatively few studies that integrate the concept of upcycling in sustainable design into university courses related to furniture design. Fewer still have integrated additive manufacturing-assisted upcycling into university courses.

***3D Printing Technology in Furniture Industry***

Nowadays, 3D printing technology is rapidly and widely used in personal and high-capacity production areas(Agashe et al., 2020).

In their study, Yang and Du (2022) examine the intricate connections between various aspects of 3D printing technology in furniture manufacturing. They explore the links between molding, product development, parts production, and product body forming. The findings of their research can serve as a useful guide for the practical manufacture of furniture products. They

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found that 3D printing can revolutionize furniture manufacturing by simplifying mold production, reducing screws and hinges, and improving fit. The authors also suggest that the awareness of application methods and advantages of 3D printing technology has hindered its promotion in the furniture manufacturing industry.

To achieve this, Hajdarevic et al. (2023) tested an acrylonitrile butadiene styrene(ABS) connector made with a fused deposition modelling (FDM) 3D printer, and compared it to a conventional beech tongue and groove connector. The results indicate that the effect of reinforcement of the connector was not recognized due to the small thickness and inadequate geometric position and arrangement of the reinforcement ABS material. The chair assembled with 3D-printed connectors could withstand the loads for seating, but failed the backrest test according to standard EN 1728:2002. The connectors need to be optimized and reinforced to withstand standard loads. Based on their results, it appears that the reinforcement of the connector was not effective due to the small thickness and poor geometric positioning and arrangement of the ABS material. Although the chair was able to handle seating loads when assembled with 3D-printed connectors, it failed the backrest test as per the EN 1728:2002 standard. To withstand standard loads, the connectors need to be optimized and reinforced.

The study by Jarža et al. (2023) discusses the positive and negative factors affecting the development of additive manufacturing technology and analyses the impact of additive manufacturing technology on the design and production of rapid prototypes and finished products in the furniture industry. Through their research, it was discovered that additive manufacturing technology will play a crucial role in the design and production of furniture in the future, despite some minor challenges in connecting different production processes. The most important advantages of 3D printing is fast prototyping, one piece production, free form designing and the use of bio-based materials and their possibility of recycling.

## Materials and Methods

The literature review method and the case study method were used in this study. A literature review involves the systematic collection and synthesis of previous research, undertaking a review of the literature is an important part of any research project(Tranfield et al., 2003). A literature review can address research questions by integrating the findings and perspectives of numerous empirical studies with a power that no single study has(Snyder, 2019).

The case study method is a field research technique used to investigate phenomena as they occur without investigators intervening significantly (Fidel, 1984). According to Becker (1971), a case study is a thorough examination of a single case that assumes that we can gain appropriate knowledge of the phenomenon under study from intensive exploration of a single case. The main objective of a case study is to arrive at a comprehensive understanding of the event under study while also developing more general theoretical statements about regularities in the observed phenomena.

Using a combination of literature review and case study methodology, this study comprehensively investigates the current state of research on furniture upcycling, the practice of upcycling cases in higher education curricula, and the use of 3D printing technology in furniture design. The integration of these methods contributes to a systematic understanding of the practical skills of furniture upcycling, and also helps to better integrate 3D printing technology into university furniture upcycling courses.

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During our preliminary research, we thoroughly examined literature and design cases related to furniture upcycling and the use of 3D printing technology in furniture design. We specifically focused on identifying effective methodologies that could be utilized in teaching furniture design in universities. Additionally, we identified basic steps and methods for integrating 3D printing technology into furniture upcycling practices.

Subsequently, an in-depth analysis of student-engaged cases in furniture upgrading and remanufacturing was undertaken to discern approaches that are not only suitable for educational settings but also yield commendable design outcomes. The upcycled furniture practice is divided into the following steps:

Step 1: Concept and Planning
Define your objectives: Determine the type of upcycled scrap furniture and the design goals and functions you want to achieve.
Gather Inspiration: Browse through a variety of furniture designs, 3D printing projects, and related industry innovations to get inspiration and learn about current design trends.
Make a Plan: Create a detailed plan that includes a design timeline, budget, materials needed, and design tools.

Step 2: Design and Modeling
Measurement and Documentation: Take precise measurements of the selected discarded furniture, documenting dimensions, structure, and any pertinent considerations.
Sketching and Concept Design: Develop sketches and concept designs based on design goals and measurement data, integrating the potential of 3D printing technology for upgrading.
Digital Modeling: Utilize 3D modeling software (such as Rhino, SolidWorks) to transform design concepts into digital models, ensuring accurate representation of design intentions.

Step 3: Material and Printing Technology Selection
Material Selection: Thoroughly research and choose 3D printing materials that are best suited for your design.
Printing Technology Selection: Select the appropriate 3D printing technology based on design requirements and material selection.

Step 4: Printing and Manufacturing
Pre-Printing Preparation: Preparing the model for printing and building the support.
Printing Process: Calibration printer, material loading, print monitoring.
Quality Control: Inspect Printed Parts.

Step 5: Assembly and Finishing
Post-Processing of Printed Parts: After 3D printing is complete, subsequent processing is performed to achieve the final look and feel.
Assembly and Integration: assembling the printed part with other materials or components to complete the furniture part.
Painting and Decoration: Painting and decorating the furniture parts according to the design requirements.

Step 6: Testing and Adjustment
Assembly Test: After the final assembly is completed, an assembly test is performed.

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Final adjustments: If any problems are found during the assembly and completion stages, final adjustments and improvements are made.

## Results

After the completion of the entire design process, a total of 5 design cases have been presented. By analysing and organizing these design cases, and drawing on the experience gained during the production process, we have summarized the following notes. Please note that the steps may differ slightly depending on the design method used.

**Table 1: Furniture Upcycling Practice Cases**

| No. | Artists | Before upcycling | Process | After upcycling |
|---|---|---|---|---|
| **1.** | Chen Si-Yu<br>Deng Yu-Tong<br>He Xin-Ying<br>Lv Jia-Jie<br>Li Wen-Jie |  |  <br>  |  |
| **2.** | WANG Huai-xin<br>Zhu Ke-Yu<br>Wang Huan<br>He Yao-Ping<br>Luo Zeng-Xue |  |  |  |
| **3.** | Liao Ping-An<br>Liu Cheng<br>Chen Ge<br>Zeng Chen<br>Lan Tian-Tian |  |  |  |

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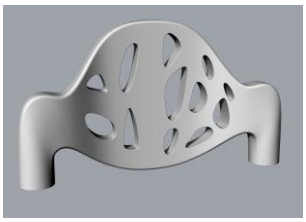
| | | | | | |
|---|---|---|---|---|---|
| **4.** | Yi Zheng-Meng<br>Wu Hai-Bo<br>Rao Min<br>Zhang Bei-Ning<br>He Qian |  |  <br>  |  |
| **5.** | Pan Sen<br>Wang Shuang<br>Wu Zhi-Qiang<br>Wu Jiu-Yi<br>Luo Si-Yu<br>Mao Xing-Long |  |  |  |

Source: Self-drawn Table

***Concept and Planning***

In the preliminary conceptual design phase, it is essential to ensure a comprehensive understanding of the original furniture's structure, functionality, and design characteristics. Innovative concepts proposed should align with the objectives of upgrading and remodeling, maintaining coherence with the furniture's original function and appearance while avoiding unnecessary complexity or compromising the product's inherent functionality. Specific goals for the upgrade, encompassing improvements in functionality, aesthetic enhancements, and sustainability aspects, must be delineated. It is imperative to ensure that the formulated objectives for upgrading and remodeling are realistic, feasible, and capable of meeting users' needs and expectations. The early stages of conceptual design should involve a thorough assessment of the resources and costs required for the project, with a rational budget devised to ensure project feasibility.

***Design and Modeling***

During the 3D modeling process, considerations should be given to the dimensions, structure, and elements requiring upgrades of the original furniture to ensure design alignment with practical requirements. Simultaneously, the characteristics and limitations of 3D printing, such as support structures and layer height, should be taken into account to mitigate potential printing issues. Accurate 3D models should be created using three-dimensional software, with model validation and optimization conducted prior to printing. Necessary modifications and adjustments should be made to ensure design accuracy and printability, thereby minimizing errors and delays during the subsequent printing process.

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***Material and Printing Technology Selection***

Material selection should be based on design requirements, ensuring that the chosen 3D printing materials possess the requisite mechanical properties, durability, and aesthetic characteristics to complement the overall style and texture of wooden furniture. Appropriate 3D printing technology should be selected based on design requirements, considering factors such as material applicability, printing speed, and precision to ensure design specifications can be met.

***Printing and Manufacturing***

During the printing process, appropriate printing parameters, such as layer height and infill density, should be set to ensure print quality and stability. Regular monitoring of the printing process is essential to ensure stable printer operation and timely detection and resolution of potential issues, thereby avoiding wastage of time and materials.

***Assembly and Finishing***

Assembled parts should be carefully fitted, ensuring coordination and integrity between 3D printed components and the original furniture. Necessary surface treatments, such as sanding and painting, should be applied to assembled parts to enhance the furniture's appearance quality and durability.

***Testing and Adjustment***

Comprehensive functional testing of the upgraded furniture should be conducted to ensure compliance with design requirements and user expectations. User feedback should be collected, and necessary adjustments and improvements made based on actual usage scenarios to enhance overall furniture quality and user satisfaction.

## Conclusions

The aim of this study is to explore the integration of 3D printing technology into upcycling furniture courses as a response to the challenges faced by the furniture industry in sustainable development. Through the preceding research content and analysis, several important conclusions can be drawn, along with prospects for future development. In the introduction to the background of the furniture industry and the issue of furniture waste, we understand that the problem of waste generated during furniture production is increasingly severe, imposing significant pressure on the environment. In this context, the concepts of sustainable design and upcycling become particularly important, and additive manufacturing, namely 3D printing, offers new possibilities for the furniture industry. The literature review delved into methods of upcycling wooden furniture and the application of 3D printing in furniture design. These studies provide theoretical support and guidance for the practical implementation of this study. It was found that upcycling furniture not only reduces waste generation but also prolongs the lifespan of furniture, enhancing resource utilization efficiency. Additionally, the application of 3D printing technology in furniture design provides new possibilities for customization and creativity. In terms of research methods and practical steps, detailed guidance was provided on integrating 3D printing technology into upcycling furniture courses. The importance of integrating theory with practice in teaching methods was emphasized, aiming to cultivate students' innovative thinking and practical skills to make them competitive in the future furniture design and manufacturing fields. Through analysis of actual student cases, it was observed that students were able to apply their knowledge successfully in practical upcycling furniture design in the classroom. This not only demonstrates the potential application of 3D

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printing technology in furniture design but also validates the effectiveness of the course teaching methods. In conclusion, this study proposes an innovative approach by exploring the issues of sustainable development in the furniture industry and advocating for the application of 3D printing technology in upcycling furniture courses. Through theoretical research and practical exploration, we have confirmed the feasibility and value of this approach.

The objective of this study was to explore the integration of 3D printing technology in a hands-on course on upcycling wooden furniture and to highlight the considerations and challenges of this process by evaluating five real-life cases. Through the literature review and the case studies, the study succeeded in identifying important issues and challenges in this process, providing valuable insights for educators and practitioners, and therefore the research objectives were achieved.

At the same time during the course of the study, several major challenges were identified. The first was the issue of compatibility between 3D printing technology and traditional woodworking processes. In the case study, despite the fact that 3D printing technology excels in terms of design flexibility and precision, there were still some difficulties when combining it with traditional woodworking processes. These difficulties consisted mainly of the adaptability of the materials and the reliability of the joining techniques. One solution to this problem is to develop 3D printing materials that are more suitable for wood and to explore more effective joining methods.

Secondly, students' acceptance and mastery of 3D printing technology is also a challenge. Despite the great potential of 3D printing technology, students may encounter difficulties in the initial learning and mastery process. For this reason, the teaching and learning process should be strengthened with more training and support for students, and more practical opportunities and technical guidance should be provided to help students better understand and apply this technology.

Finally, the existing teaching methods are inadequate in combining traditional processes with emerging technologies. In order to solve this problem, it is recommended that more emphasis be placed on the practical aspects of the course design, adopting a project-based teaching method and encouraging students to apply 3D printing technology in real projects. At the same time, the training of teachers should be strengthened so that they can better instruct students.

In conclusion, through in-depth analyses of actual cases, this study not only reveals the potential of 3D printing technology in upcycling wooden furniture, but also proposes specific solutions to these challenges. It is hoped that these findings and recommendations will inform future educational practices and contribute to the promotion of the application of 3D printing technology in wood furniture upcycling.

In conclusion, although this study has made positive achievements in integrating 3D printing technology into furniture upcycling courses, there are still some technological and pedagogical limitations to overcome. Future endeavours could involve further enriching the course content, exploring more cases of furniture design and upcycling, and expanding the application areas of 3D printing technology in furniture manufacturing. Through the practical exploration of this study, new ideas and methods have been provided for furniture design education in Chinese

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vocational colleges, aiming to contribute to the sustainable development of the furniture industry.

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