Exploration of Practice Teaching Mode of Product Design Based on Three-dimensional Printing Technology

Wei Shu¹*, Fuliang Sun²

¹Art school, Huangshan University, HuangShan, AnHui, 245041, China
²Art school, Huangshan University, HuangShan, AnHui, 245041, China

*Corresponding author’s e-mail: shuwei@hsu.edu.cn

Abstract. As a highly interdisciplinary and practice major, product design is expected to achieve the cultivation of innovative talents with artistic accomplishment, engineering knowledge, business awareness and design skills within limited learning time. Technology and art are regarded as the core of its cultivation. In the traditional industrial processing system, mass industrial production is taken by product design practice as the premise. Nevertheless, the maturity of rapid prototyping system represented by three-dimensional printing technology and its combination with whole-process digitalization and intelligent production bring about a great reduction in individualized customization and flexible production costs, which leads to new development opportunities for product design practice. This paper is devoted to the discussion of the practice teaching mode of product design in the context of three-dimensional printing technology.

1. Introduction

The third industrial revolution, represented by three-dimensional printing technology and marked by the application of digitization, artificial intelligence manufacturing and new materials, has arrived, while a brand new industrial era will be created by three-dimensional printers, the Economist magazine said in April 2012. On May 8th, 2015, the State Council promulgated the first ten-year action guiding principle of Made-in-China 2025, which put forward the requirements of insisting on "innovation-driven, quality-first, green development, structural optimization and talent-oriented"[1]. Have been mentioned repeatedly six times in this document, three-dimensional printing technology runs through the key sections of background introduction, improvement of national manufacturing innovation capacity, in-depth integration of informatization and industrialization, and breakthrough development in key areas. Integrated into the main line of promoting intelligent manufacturing, it has become a crucial link of the strategic plan [2]. At the same time, the document also highlights the significance of talent demand, emphasizes to improve the talent cultivation system from R&D, transformation, production to management of Made-in-China and focuses on the cultivation of "three types of high-end talents in shortage": High-level professional and technical talents and innovative talents, outstanding entrepreneurs and high-level management talents and those are proficient in both manufacturing technology and information technology.
2. Characteristics and Advantages of Three-dimensional Printing Technology

Three-dimensional Printing (3D Printing) technology is an object construction technology based on digital model files with bondable materials such as powder metal or plastic by printing layer by layer \[3\]. As a rapid prototyping technology of relative maturity at present, it forms three-dimensional solid model through material stacking by virtue of mainly the method of additive manufacturing, with the American patent on the layered manufacturing method to form topographic maps proposed by J. E. Blanther in 1892 as its technical prototype \[4\]. After that, Charles W. Hull invented the world's first 3D printer in 1983 and founded 3D Systems in 1986, which developed the current general STL file format and launched the SL-based 3D industrial printer in 1988. Subsequently, three-dimensional printing and molding technologies such as SLA (Stereo lithography Appearance), SLS (Selected Laser Sintering), FDM (Fused Deposition Modeling), 3DP (3D Printing) and PUG (vacuum casting) came into being. Compared with traditional manufacturing methods, the revolutionary change of production and processing concept brought about by three-dimensional printing technology, the major technical features of which are manifested as: Rapid free prototyping due to the absence of molds in manufacturing equipment; Full digitalization and high flexibility of the production process; Capable of manufacturing almost infinitely complex geometric structures; Current technology can be applied to the manufacture of materials of a number of varieties; Capable of achieving the arbitrary composite manufacturing of multi materials (e.g. functionally gradient structures). These features have brought three-dimensional printing technology with the following advantages in actual production:

Firstly, apart from shortening the processing and manufacturing cycle, three-dimensional printing technology can also bring a significant reduction in production costs. In particular, it enables human beings to achieve freedom in the field of processing by breaking through the limitations of traditional processing and manufacturing methods on processing of complex shapes.

Secondly, three-dimensional printing technology has been widely applied in special fields including medical, aerospace, jewelry manufacturing and so forth. For example, in the medical field, the Ninth People's Hospital affiliated to Shanghai Jiao Tong University manufactured an artificial pelvis with three-dimensional printing technology and successfully transplanted it into the patient's body to promote its rehabilitation.

Thirdly, with high plasticity, the finished products produced by three-dimensional printing technology can be applied to both two-dimensional and three-dimensional. Layer-by-layer printing will be adopted in processing, while the processing accuracy of the printer can be as accurate as 0.01 mm per layer.

Finally, three-dimensional printing technology demonstrates great advantages in individualized customization. For traditional industrial manufacturing, which achieves product cost reduction through mass production, individualized production is difficult to realize. However, the possibility of low-cost individualized customization has been brought about by three-dimensional printing technology.

3. Comparison of Mainstream Three-dimensional Printing Equipment

Three-dimensional printers based on different technologies including "SLA, SLS, SLM, FDM, DLP, MJM..." with have assumed increasingly maturity in recent years, while industrial equipment with large print size, high accuracy, wide materials compatibility and desktop equipment with smaller print size, acceptable accuracy and single print material are constantly emerging. However, desktop printing equipment is widely adopted and accepted by users in teaching activities that are limited by the cost of equipment and consumables. Printers of this type are mostly based on fused deposition molding (FDM) and photosensitive resin selective curing technology, the latter of which is divided into two categories: stereo lithography appearance (SLA) and digital light processing (DLP). We are now carrying out a comparison of desktop three-dimensional printers based on FDM, SLA and DLP technologies, as shown in table 1.
Table 1. Comparison of SLA, FDM and DLP Equipment

| Name          | Stereo Lithography Appearance | Fused Deposition Molding | Digital Light Processing |
|---------------|--------------------------------|--------------------------|--------------------------|
| Abbreviation  | SLA                            | FDM                      | DLP                      |
| Consumable    | Liquid photosensitive resin    | Wire such as ABS, PLA, etc. | Liquid photosensitive resin |
| Method        | Laser beam (point curing)      | Heating devices (line extrusion) | Digital projection light source (surface curing) |
| Example       | ![Example Image](image.png)    | ![Example Image](image.png) | ![Example Image](image.png) |

The size of FDM three-dimensional printer with flexible structure can be either large or small. Thanks to the low price of equipment and consumables, it has gained considerably high popularity. Nevertheless, it assumes poor stability and slow printing speed in the production of large molding size. The major molding way of extruding consumables through the extrusion head brings obvious step effect. In addition, the processing accuracy and fluidity are both affected by the diameter of the nozzle and are mutually restricted.

The SLA and DLP three-dimensional printers which adopt light molding method are better in accuracy. Among them, DLP emits scattered sector light, while SLA emits laser of and approximately straight line, which determines its performance in accuracy is better than DLP.

SLA three-dimensional printer also completes printing through the motion of optical axis. Despite that it can print large size in theory, the current technology fails to support the manufacture of large SLA three-dimensional printers. It mainly cures the material through the laser points in forming, which can achieve higher processing accuracy.

The digital light source of projector is adopted by DLP three-dimensional printers, which is different from SLA three-dimensional printer which uses laser and cures materials with scattering sector light. The accuracy will be difficult to be ensured if the size is enlarged.

In General, in terms of molding size: FDM > SLA ≈ DLP; in terms of molding accuracy: SLA > DLP > FDM; in terms of equipment price: SLA > DLP > FDM; in terms of price of consumables: SLA ≈ DLP > FDM.

In accordance with the equipment and its application introduced at various additive manufacturing exhibitions in recent years, the relevant equipment of Fused Deposition Molding (FDM) has achieved the expected goal of being usable, use-friendly and cost-effective. In addition to meeting the application requirements of rapid prototyping in product design field in terms of accuracy, it also presents satisfactory printing time and stability, which makes it sufficient to customize small batch and non-durable design samples. Compared with other types, the price of FDM three-dimensional printer equipment is greatly reduced yet the high stability of consumables is maintained. Due to the lack of technical barriers, the post-processing and surface treatment processes of processed products are becoming increasingly mature, while the processing time can be shortened by simultaneous printing of multiple devices when necessary. As the most simple and direct way to meet the demanding fields including three-dimensional printing services, assistant education and teaching and so forth, the relatively improved supporting resolutions in technology and equipment are provided by FDM three-dimensional printers.
4. Application in the Field of Education
With its characteristics and advantages, three-dimensional printing technology has been widely applied in fields of rapid development of new products, individualized manufacturing, etc. People take advantage of the technology to produce extremely complex structure that fails to be coped with by traditional technology and make design models and samples to achieve the optimization of design and the improvement of product function. Providing new teaching methods for the education industry at the same time, three-dimensional printing technology can be applied to most disciplines as a general technology, including various types of education such as formal learning, informal learning and training. It is especially suitable for the related fields of design and engineering or for the areas where there is a demand for rapid prototyping, as shown in table 2. Except for the convenience of assistant teaching for various disciplines, three-dimensional printing technology is also conducive to stimulate and promote students' innovative design. More importantly, the mastery of three-dimensional printing technology will exert a far-reaching impact on their technical literacy and future career development.

Table 2. Application of Three-dimensional Printing in Teaching of Various Disciplines

| Subject       | Majors and fields                                                                 | Application method                                                                 |
|---------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Historiography| Fields including archaeology, cultural relics, museums, etc.                      | Help in the restoration of historical relics, the reproduction of fragile articles, the production of diode models, etc. |
| Natural Science| Fields including Mathematics, Physics, Chemistry, etc.                           | Production of three-dimensional geometric blocks, molecular models, etc.             |
| Engineering   | Fields including architecture, aerospace, electronics, machinery, etc.            | Production of scale model, rapid prototyping and replacement parts as well as small batch trial production, etc. |
| Agronomy      | Fields including forestry, zoology, aquatic products, etc.                       | Production of animal and plant models, garden sand tables, etc.                     |
| Medicine      | Fields including basic medicine and clinical medicine, etc.                      | Production of models of molecules, viruses, organs, etc., Processing of artificial joints and organs, etc. |
| Management    | Fields including real estate development and management, land resource management, etc. | Production of various sand table models for properties, terrain, city, etc.          |
| Art           | Fields including animation, sculpture, design, etc.                              | Production of 3D models of works, design prototypes, etc.                           |

5. Three-dimensional Printing and Product Design Education
Practice teaching in product design teaching takes teachers putting forward practice projects and leading students to carry out design practice training focusing on the project as its major pattern, while low-cost three-dimensional printing technology promotes the popularization of rapid prototype design schemes in design practice. Before three-dimensional printers being introduced into practice teaching, CNC equipment was mainly adopted in rapid prototyping of product design. However, for all that such equipment is capable of realizing the production and processing of design samples, it is expensive and the cost of its consumables is relatively high as well. In addition, competent professionals are required to solve the related technical problems arising in the transformation from CAD to CAM of design schemes, while the operators of control equipment in processing are also expected to undergo special training before dealing with complex technical parameters. Hence, in spite a number of colleges and universities have invested a lot in their product design teaching practice in the early stage to complete the relevant supporting system, only a few colleges with sufficient commercial project support and favorable communication with production enterprises are capable of completing the whole teaching practice process. What’s more, resulting from the restrictions of engineering literacy of product design students, they tend to withdraw from these complex practice processes, while the high cost also leads to rapid prototyping practice eventually become a link of internship, in which most of the students' design schemes for practice teaching stay merely at design drawings.

Having been devoted to the research of three-dimensional printing technology since 1992, the Laser Rapid Prototyping Center of Tsinghua University is the earliest institution committing to the field in China, accompanied by the subsequently gradual carrying out of relevant researches in other areas of China. Purchasing related equipment in 2010 and starting the exploration of the application of related technology in the teaching practice of product design, relevant practice of the university has been promoted by virtue of the relatively mature and cost-effective FDM technology.
The introduction of rapid prototyping technology supported by three-dimensional printing enriches the link of practice in product design teaching, while it is especially worth noting that it enables the design scheme to break through the boundaries of the drawings and allows students to carry out a series of practices such as geometric model, rapid prototyping and sample trial production under the guidance of teachers. Based on this, we make the following amendments to the design practice process in teaching, as shown in Figure 1:

Figure 1. Design Practice Process before and after the Introduction of Rapid Prototyping in Teaching

Firstly, the practice of rapid prototyping is added. A number of advantages of FDM technology enable students to complete simple design prototype in limited teaching time, which focuses on the overall pattern and basic structure without the demand for surface treatment. It is mainly applied to the research of structure, the optimization of schemes, the revision of design and the assistance of evaluation of design scheme upon the completion of practice projects. Digital design is adopted in the whole process of practical design and guidance of teachers and students, merely requiring that the digital and analog demand of rapid prototyping is taken into account in the process of CAD.

Secondly, the innovation of product form will be more concerned by the design schemes. The convenience of three-dimensional printing in complex modeling achieves a significant reduction in the energy investment in engineering drawing and the favorable workability of product modeling in design practice. The controversial patterns or nodes can be presented in the form of physical objects by designers resorting to three-dimensional printing technology, so that the design schemes can be compared through all-round perception and finally enables to select the design scheme which are difficult to be realized in drawings.

Furthermore, the practice of rapid prototyping is conducive to the cultivation of students' favorable engineering habits. Compared with traditional processing, despite that rapid prototyping is subject to fewer engineering constraints, plenty of engineering problems still have to be taken into account in the process of converting the design from paper to physical objects, such as the specific scale of design schemes, the human-machine relationship of design components, the coordination methods between different components, the operation mode of simple mechanisms, etc. Merely focusing on the visual proportionality of effect diagrams in the past, the introduction of rapid prototyping will require students to carry out the construction of design schemes as well as the study of product nodes and detailed structures in line with the actual size of products since the initial stage of design, which indicates that the design schemes will go beyond the appearance.

Finally, rapid prototyping achieves the promotion of design evaluation accuracy, design guidance and the materialization of design schemes. In the design evaluation, the comparison between object and drawing as well as the combination of effect diagrams and rapid prototyping demonstrate the state of nodes and mechanisms, so that the accuracy of design expression can be improved by comprehensively exhibiting the design schemes. By right of their convenience in storage, exhibition and research, objects of rapid prototyping is capable of facilitating the communication between
students and assumes a considerable guiding and reference significance for the subsequently design practice of the similar type.

6. Conclusion
By virtue of the incomparable advantages of traditional manufacturing methods, accompanied by the rapid development of related equipment of three-dimensional printing technology are new opportunities brought to product design education. In addition to materializing students' design practice, the technology can also enable designers genuinely perceive their creativity and conduct the experience and evaluation in person of their design. Considering the inevitable shortcomings and limitations of the current three-dimensional printing technology itself, its subordinate status in product design education has to be clarified. That is to say, three-dimensional printing technology is merely a path to realize the rapid prototyping technology and an approach providing assistance for designers to carry out design optimization and scheme evaluation. In addition, students should be reminded that three-dimensional printing, as the representative of additive manufacturing, should only be regarded as a processing method, while its processing components are not likely to actually replace the mass products due to the constraints of material, surface technology and accuracy. Therefore, it is inappropriate to ignore other processing methods because of it. At the same time, various materials and engineering knowledge should be absorbed in order to realize the continuous improvement of knowledge system. Besides, we are also reminded of the significance of focusing on cutting-edge technology and mastering the pulse of the times by the change of practice teaching modes of product design brought about by three-dimensional printing technology. As an emerging technology going back to dreariness after the uproar, three-dimensional printing assumes a number of advantages worthy to be affirmed. Despite that researches on it have never stopped in the relevant fields so far, there is still a long way to go before it achieves the genuine counter-balance with traditional manufacturing. The impetuous and speculative attitude as well as blindly exaggeration and promotion of some capital in dealing with it will only lead to the opposite effect.

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