The Analysis of Three Dimension Printing Technology in Parametric Architectural Design

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Abstract

In today's architectural design field, parametric design and Three-dimensional Printing Technology (3D Printing Technology) are both cutting-edge technologies that are receiving a lot of attention. There have been a number of case studies on the application of parametric design and 3D Printing Technologies in the field of architecture. However, in-depth research on the combination of these two remains relatively limited. Researchers have begun to focus on how to combine 3D Printing Technology with parametric architectural design in order to utilize the advantages of both to create more innovative architectural designs.This study explores the cross-application of 3D Printing Technology with parametric architectural design. Firstly, 3D Printing Technology is a digital construction technology that constructs designs based on digital models by printing layer by layer. After that, this paper introduces the characteristics of parametric building design. Usually parametric buildings have complex building skin shapes, therefore, parametric buildings usually mean higher construction difficulty and longer construction time. While the introduction of 3D Printing Technology can provide technical support for parametric building design, 3D Printing Technology has great potential for application in realizing complex and personalized building forms. Finally, the parametric design of Lotus Building is taken as a case study. It shows the application of 3D Printing Technology in parametric architectural design and demonstrates the technical support that 3D Printing Technology brings to the field of parametric architectural design. In the end, it is hoped that the synergistic development of 3D Printing Technology and parametric architectural design can be further promoted.

Keywords: Three-dimensional Printing Technology; Parametric; Architectural Design; Lotus Building

Introduction

Three-dimensional Printing Technology (3D Printing Technology) is a rapid prototyping technology, the core idea of which originated in the late 1800's and took shape in the mid-1980's. Three Dimensions Printing Technology is the process by which materials are thickened and stacked or melted to form a three-dimensional object (Mpofu et al., 2014; Ramya & Vanapalli, 2016: 396-409). 3D Printing Technology is the process of thickening and stacking or melt molding materials to form a three-dimensional object. Unlike traditional processing methods, it does not require molds or manual operation, and can generate solid objects directly from design drawings, greatly improving productivity and manufacturing accuracy. 3D Printing Technology covers a wide range of different process forms, such as light curing, fused deposition, and powder-bed sintering, etc., with different materials and principles used in the different forms of the process .

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3D Printing Technology is used in a wide range of applications including (Manero et al., 2019: 1641), but not limited to, aerospace, automotive, medical research, architectural design, education, and training. The applications include but are not limited to aerospace, automotive manufacturing, medical research, architectural design, education and training. In the aerospace industry, 3D Printing Technology is used to produce lightweight aircraft components and engine parts, improving the performance and efficiency of aircraft (Bozkurt & Karayel, 2021: 1430-1450). In medical research, 3D Printing Technology is used to produce simulated organs, body parts, and surgical models for medical research and surgical training. In the field of architectural design, 3D Printing Technology is used to build new types of architectural structures and landscape sculptures, realizing the diversity and innovation of architectural design. With the continuous development and application of 3D Printing Technology, its application prospects in manufacturing, medical and healthcare, culture and education are getting broader and broader (Bozkurt & Karayel, 2021: 1430-1450; Manero et al., 2019: 1641; McMenamin et al., 2014: 479-486.). At present, governments and enterprises are increasing R&D and investment in 3D Printing Technology to compete for the leading edge of the technology. At the same time, it is also necessary to pay attention to issues such as intellectual property protection and security risks involved in 3D Printing Technology to promote the healthy development and application of the technology.

Figure 1 The Guggenheim Museum Bilbao
Source: https://www.archdaily.com/422470/ad-classics-the-guggenheim-museum-bilbao-frank-gehry

3D Printer as its core equipment, is a set of mechanical, computer technology and intelligent control and other complex electromechanical as a whole, mainly by high-precision mechanical systems, CNC systems and molding technology and other subsystems. American Charles Hull invented the first ever 3D printer, which opened the research of 3D Printing Technology. Contrary to traditional material manufacturing techniques, 3D Printing Technology follows the principle of layer-by-layer pugilism, integrating design and manufacturing while moving away from traditional tools and machine tools, making complex skin shapes a reality.

Architectural works using parametric design usually have complex skin shape composition, and more often use more exaggerated expression, with strong visual impact. In recent years, with the development of digital technology, parametric architectural design is gradually known by the field of architectural design (Na, 2021; Turrin et al., 2011: 1-16). The core idea of parametric architectural design is to turn all the elements of architectural design into the variables of a certain function, and by changing the function, or changing the algorithm, designers are able to obtain different architectural design solutions. In the early stage of the development of parametric architectural design, architects often complete the scheme design by hand, and then use the parametric design method to make the model. For example, as shown in Figure 1, Frank Gehry completed the Guggenheim Museum in 1997. In the face of such a complex architectural form, the traditional two-dimensional drawing technology has been unable to help, need to rely on three-dimensional digital technology can be realized, which led to the traditional two-dimensional design technology to three-dimensional design technology change.

Figure 2 Keydar Aliyev Cultural Center
Source: https://www.archdaily.com/448774/heydar-aliyev-center-zaha-hadid-architects

Parametric architectural design has continued to evolve since then, and pioneering firms such as Zaha are thoroughly applying the idea of parametric design, combining design ideas with design tools to generate new architectural forms. For example, as shown in Figure 2, Zaha Hadid's Keydar Aliyev Cultural Center in Azerbaijan, completed in 2013, the idea of parametric design is carried through the entire conceptual, programmatic and even construction drawing stages.

It is worth noting that the workflow of parametric design and digital fabrication can require considerable investment, mainly in the economic cost of construction versus the time cost of construction. Individualized and customized parametric architectural design often means that parametrically designed buildings require more challenging construction (Monedero, 2000: 369-377.). This is one of the main reasons why there are fewer buildings of this type. The introduction of 3D Printing Technology has provided an enabler for the development of parametric architecture. Parametric design allows architects to use parameters and algorithms to create highly customized designs. This, combined with the flexibility of 3D Printing Technology, allows buildings to be quickly and precisely customized to specific needs, including complex geometries and structures. Parametric design combined with 3D Printing makes it easier to realize complex geometries. While traditional construction methods may not allow for the easy realization of some complex designs, 3D printing is able to build almost any shape layer by layer. Parametric designs can be customized and produced with 3D Printing Technology (Besklubova et al., 2021). The digital manufacturing process reduces the complexity of constructing architectural works, increases construction efficiency, and reduces production costs. The combination of parametric design and 3D Printing Technology brings greater scope for innovation in the field of architecture, while providing more efficient, sustainable and customized architectural solutions.

3D Printing Technology

1. Key elements of 3D Printing Technology

The core tool of 3D Printing Technology is the 3D printer.The complete system of 3D printer is an integrated system of machinery, control and computer technology. Its system mainly consists of X-Y-Z motion system, nozzle or laser, data pre-processing module, numerical control module, molding environment module and so on (Sahana & Thampi, 2018).

2. Workflow of 3D Printing Technology

As shown in the Figure 3, the main process of 3D Printing Technology.

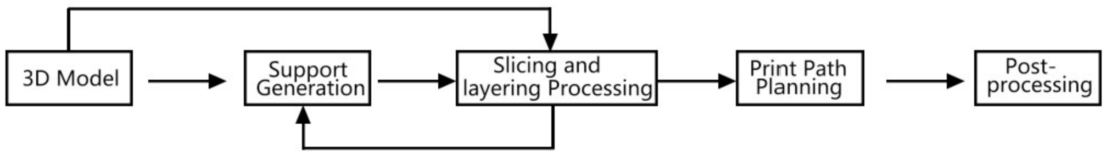

Figure 3 The main process of 3D Printing Technology
Source: Author’s own work

(1) Three-dimensional model generation: Now the modeling of a variety of ways, generally the use of professional modeling software or three-dimensional scanner, some of which may be the scanning of the point cloud data obtained, there may be modeling generated by the NURBS surface information, etc., but the data may not be obtained by the 3D printer to identify the file format, so no matter what kind of 3D modeling software generated by the 3D models need to be So no matter what kind of 3D modeling software is used to generate 3D models, they need to be converted into .stl or .obj file formats that can be read by 3D printers.

(2) Generation of support structure: the generation of support structure can be after the slice layering, but also before the slice layering, simple and effective support structure can not only improve the probability of success of the 3D model printing, but also reduce the waste of expensive printing materials (Bozkurt & Karayel, 2021: 1430-1450).

(3) Slicing and layering processing: slicing and layering is to layer the complex 3D model to get a simple 2D contour, so as to facilitate the subsequent data processing.

(4) Printing path planning: the polygonal contour obtained by slicing and layering needs to be filled internally, and after filling, the layer forms a real physical thin layer, which is printed layer by layer until the printing is completed, so it is necessary to plan out the specific printing path and make reasonable optimization to get faster and better printing results.

(5) Post-processing: The post-processing of 3D printing refers to the surface of the printed solid model as well as special details, and the purpose of doing so is to improve the accuracy of the model surface. Post-processing of different printing materials is different, but the post-processing is generally divided into three steps: first, the model from the 3D printer; second, remove the model's support structure, there is no support structure does not need to be dealt with; third, the details of the model part of the fine processing (such as sanding and polishing), the print material for the FDM-type ABS and PLA 3D printer printing is completed first after the printed Three-dimensional objects first use a spatula to remove the product from the base of the flat plate, with scissors and other tools to remove excess support parts, the next step is to use other power tools for fine engraving, and then finally polishing, commonly used inexpensive way is to use abrasive paper for rubbing.

3. Summary of 3D Printing Technology

Three-dimensional printing technology relies on the core tool, the three-dimensional printer, to build an integrated system that encompasses mechanical, control, and computer technologies. The system includes key components such as an X-Y-Z motion system, a nozzle or laser, a data preprocessing module, a numerical control module and a molding environment module. The workflow consists of key steps, starting with the generation of a 3D model through specialized software or scanners, followed by the creation of a support structure to improve print success and material utilization. The slicing and layering process simplifies complex models and paves the way for optimized print path planning. Post-processing involves a series of complex steps, including the removal of support structures and fine-tuning to improve the accuracy of the model's surface, depending on the print material used.3D printing is, in general, a technology that requires the input of data in order to accurately output a highly precise and specifically designed product.

The aim of this thesis is to explore and analyze the integration of 3D printing technology in parametric architectural design. The combination of these two cutting-edge technologies has caused a paradigm shift in the field of architecture, influencing the design process, fabrication techniques, and architectural methodologies, among others. By elucidating the key elements of 3D printing technology and detailing its workflows, this thesis aims to provide architects, designers and researchers in the design field with valuable insights into the transformative potential of 3D printing in the field of parametric building design. By providing insight into the workflows and considerations involved, this thesis helps to foster innovation and development in architectural practice.

Parametric Building Design Overview

1. Parametric architectural design.

Parametric design is a kind of parametric design, that is, the design is parameterized, in other words, the design is controlled by variable parameters, each parameter controls and describes a certain type of important property of the design result, and the design result will change when the parameter is changed. Parametric design can be used in many fields, for architectural design, parametric design can be used for parametric control of building skin, parametric design of structural nodes, and parametric control of existing forms, etc., and this paper is mainly about the use of parametric methods in the design and generation of architectural shapes.

2. The main technical route of parametric architectural design

Parametric architectural modeling design involves a number of links, mainly the following three main steps: the designer first establishes the model (to complete the setting of parametric variables), and then completes the setting of the logic and algorithms for generating the architectural scheme, and finally obtains the corresponding design scheme. The success of these steps determines the quality and efficiency of the final product (Hollberg & Ruth, 2016: 943-960.; Monedero, 2000;: 369-377.

Schumacher, 2015; Turrin et al., 2011656-675.).

(1) In the modeling stage, in the parametric design stage, professional p arametric design tools are used to subdivide the model and set parameters, and finally a controllable modeling form is derived.

(2) Through computer simulation and emulation, the generation logic and algorithm of the building are set to generate a building program that conforms to the arithmetic logic. The process will involve feedback and modification of the design until the most satisfactory program design is generated.

(3) Use 3D printing and other construction technologies to complete the machine to make the parameterized design scheme.

Advantages of 3D Printing Technology for Parametric Styling Applications

Parametric designs can be customized for production by 3D Printing Technology. The digital manufacturing process reduces the complexity of constructing architectural works, improves construction efficiency and reduces production costs. The combination of parametric design and 3D Printing Technology brings more room for innovation in the field of architecture

1. Material saving. There is no need to eliminate edges and corners, which improves the utilization of materials and reduces costs by eliminating production lines.

2. Higher precision and complexity can be achieved, making it possible to produce very complex parts that cannot be produced using traditional methods;

3. does not require traditional tools, fixtures, machine tools or any mold, you can directly computer any shape of the three-dimensional CAD graphics to generate physical products;

4. It can be automatic, fast, direct and relatively accurate three-dimensional design in the computer into a physical model, or even directly manufacturing parts or molds, thus effectively shortening the product development cycle;

5. 3D printing does not require a centralized, fixed manufacturing plant, characterized by distributed production; can be shaped within hours (Bozkurt & Karayel, 2021: 1430-1450), it

allows designers and developers to realize the leap from the floor plan to the physical; it can print assembled products, thus reducing the assembly costs, and can even challenge the mass production methods.

Application of 3D Printing Technology in the Field of Parametric Styling Design - Example of an Architectural Design Work with Parametrically Generated Lotus Elements

The use of 3D Printing Technology and modeling systems to create diverse lotus forms resulted in a high-quality, efficient construction solution for this type of building structure. The specific process is as follows:

1. Establish the original 3D model of the lotus flower: As shown in Figure 4, use computer-aided design software to establish the initial 3D model of the lotus flower (Yu et al., 2015L: 83-101.; Yu & Gero, 2016: 289-302.). And the design parameters and make repeated modifications, the use of modeling language for parametric design of the model, in order to meet the diversity of needs, but also for different kinds of lotus flower model parameter range settings.

Figure 4 Model testing and correction
Source: Author's own work

2. Model testing and correction: This stage utilizes 3D Printing Technology to quickly produce the model into an observable sample and verify it with physical mechanics testing (such as load-bearing capacity, stiffness, etc.) or real environment experiments. Based on the test results, necessary optimizations and modifications need to be made. Based on the evaluation of the model, designers continue to enhance and improve the model. In addition, feedback on the model is monitored while the product is being operated manually or automatically to determine if additional market feedback and design re-improvements are needed (Yu & Gero, 2016: 289-302.).

3. Solution Production: This stage is where the final parametric design and printing process is executed and the final Lotus Element design solution needs to be produced through an automated production process (Figure 5).

Figure 5 Solution Production
Source: Author's own work

Conclusion

3D Printing Technology in the field of parametric design is constantly practiced and developed, and the technology is getting more and more advanced and mature. 3D Printing Technology is ultimately a kind of digital construction technology, which is a brand new design logic and construction mode, and it is highly suitable for the needs of parametric building design, which has complex architectural forms and high construction difficulty. 3D Printing Technology is highly compatible with the demand of parameterized building design, which has complex building form and high construction difficulty. 3D Printing Technology can greatly improve the construction efficiency of parametric buildings and also greatly reduce the construction difficulty of such buildings, which subverts the traditional construction industry to a certain extent, and will certainly provide strong technical support for the development of parametric buildings in the future.

References

Besklubova, S., Skibniewski, M. J., & Zhang, X. (2021). Factors affecting 3D Printing Technology adaptation in construction. *Journal of Construction Engineering and Management*. 147 (5), 04021026.

Bozkurt, Y., & Karayel, E. (2021). 3D Printing Technology; methods, biomedical applications, future opportunities and trends. *Journal of Materials Research and Technology*. 14, 1430-1450.

Hollberg, A., & Ruth, J. (2016). LCA in architectural design—a parametric approach. *The International Journal of Life Cycle Assessment*. 21, 943-960.

Manero, A., Smith, P., Sparkman, J., Dombrowski, M., Courbin, D., Kester, A., Womack, I., & Chi, A. (2019). Implementation of 3D Printing Technology in the field of prosthetics: Past, present, and future. *International Journal of Environmental Research and Public Health*. 16 (9), 1641.

McMenamin, P. G., Quayle, M. R., McHenry, C. R., & Adams, J. W. (2014). The production of anatomical teaching resources using three-dimensional (3D) Printing Technology. *Anatomical sciences education*. 7 (6), 479-486.

Monedero, J. (2000). Parametric design: a review and some experiences. *Automation in Construction*. 9 (4), 369-377.

Mpofu, T. P., Mawere, C., & Mukosera, M. (2014). The impact and application of 3D Printing Technology.

Na, S. (2021). Case analysis and applicability review of parametric design in landscape architectural design. *Journal of the Korean Institute of Landscape Architecture*. 49 (2), 1-16.

Ramya, A., & Vanapalli, S. L. (2016). 3D Printing Technologies in various applications. *International Journal of Mechanical Engineering and Technology*. 7 (3), 396-409.

Sahana, V., & Thampi, G. (2018). 3D Printing Technology in industry. 2018 2nd International Conference on Inventive Systems and Control (ICISC),

Turrin, M., Von Buelow, P., & Stouffs, R. (2011). Design explorations of performance driven geometry in architectural design using parametric modeling and genetic algorithms. *Advanced engineering informatics*. 25 (4), 656-675.

Yu, R., Gero, J., & Gu, N. (2015). Architects' cognitive behaviour in parametric design. *International Journal of Architectural Computing*. 13 (1), 83-101.

Yu, R., & Gero, J. S. (2016). An empirical basis for the use of design patterns by architects in parametric design. *International Journal of Architectural Computing*. 14 (3), 289-302.