Comparative Study on The Generation of Fused Deposition Modeling Support Structures

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Abstract. Fused Deposition Modeling (FDM) is a 3D printing technique used to print thermoplastic materials layer by layer. It involves generating support structures under the suspended part. The support structure can prevent the suspended part from collapsing due to gravity. The support structure can be artificially added, but this method is time-consuming and easy to waste materials. A better approach is to use software to automatically generate support structures. Currently, there are various slicing software options with support structure generation algorithms. However, these support structures may have different defects. Excessive support material, for example, leads to long printing times and difficulty in removal, which can result in low product accuracy. Stable, robust, and easily removable support structures that conserve material can be achieved only by using software that optimizes adherence to the model. In this study, this study simulate and test existing support generation algorithms. By comparing the parameters of the support structures, this study aim to identify the advantages and disadvantages of different software. This will help researchers determine the most suitable software for printing different models.

Keywords: 3D Printing, Support Structures, Slicing Software

1 Introduction

Nowadays, 3D printing technology uses many technical methods, such as: mechanical engineering, material engineering and so on [1]. 3D printing technology encompasses several mainstream methods, including selective laser sintering (SLS), selective laser melting (SLM), electron beam melting (EBM), and fused deposition modeling (FDM) [2]. Each of these technologies has its own material manufacturing methods. This study mainly research some support structures of FDM. First of all, as shown in Figure 1, the printing materials used by FDM are polylactic acid and ABS plastic. This technique uses a heating nozzle to extrude filamentous material, such as hot plastic and some wax or metal fuses, evenly spraying the extruded material on each layer in a desired trajectory and melting deposition at a desired rate. In the process of FDM, there are many technologies that will determine the final success or failure, and the support structure is an important point [3]. As shown in Figure 2, this process is the final molding of

Y. Yue (ed.), *Proceedings of the 2024 International Conference on Mechanics, Electronics Engineering and Automation (ICMEEA 2024)*, Advances in Engineering Research 240,
https://doi.org/10.2991/978-94-6463-518-8_17

plastic material layer by layer. If the upper layer area is larger than the lower layer during this process, a support structure is needed to ensure smooth printing [4,5]. Otherwise, the superstructure collapses due to gravity. Nowadays, there are many algorithms such as S-type acceleration and deceleration algorithm and BP-PID algorithm [6]. Shi, X. Use analysis methods to obtain support process parameters, and then compare the performance of support structures in different algorithms to better remove some support [7]. Li, Y. studies on melt deposition 3D printer control system and process parameter optimization provide us with Bresenham linear algorithm and so on [8]. This paper will explore the different parameters of FDM type column support and tree support in Slic3r and Meshmixer and consider which support is more reasonable under what circumstances.

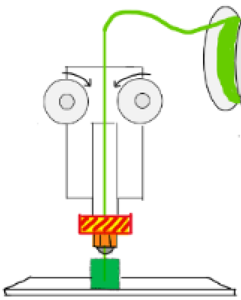

Fig. 1. FDM technology schematic diagram (Photo/Picture credit: Original)

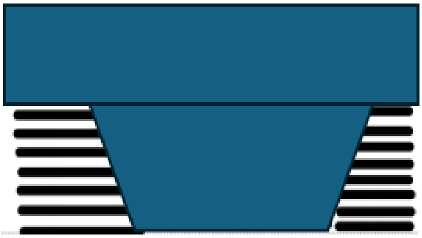

Fig. 2. FDM process principle and support (Photo/Picture credit: Original).

How to design a reasonable support structure is an important problem that 3D printing equipment using FDM process needs to face. The algorithm for generating the support structure should be optimized for material saving under the premise of ensuring the printability of the object model. Therefore, it can be summarized into two main issues: (1) Find the parts that need support. (2) Generate support structure

There are many ways to deal with these two problems. In the aspect of finding the area to be supported, the common method involves selecting all surfaces of the 3D object model that have a downward-facing normal and an angle with the horizontal plane that indicates the need for support. Many existing slicer engines, such as Ultimater's Cura and Autodesk's MeshMixer, use this approach. Another method is to make a Boolean difference between two successive slices.

There are two methods to generate the support structure, one is to manually add the support in the modeling software, and the other is to automatically generate the support structure through the slicing software algorithm.

(1) Manual addition of support: Designers manually operate on the 3D model building software. In the mode of installation and ligand, parts can be manually added to assist the model forming, but this operation has high requirements for technicians, low efficiency and large errors. These factors lead to the need for printing manpower and material resources is very much, cost-effective is relatively low.

(2) Automatic generation mode of slicing software: automatically detect the part that needs to add support structure and generate the corresponding support structure through the algorithm. This generation mode has high requirements for computer configuration and algorithm designed by technical personnel.

2 Literature Review

The design of a lightweight tree-shaped internal support structure for fused deposition modeling (FDM) 3D printing shell model. The research method is to propose a hybrid method combining improved particle swarm optimization (PSO) and greedy strategy for topology optimization of tree support structure. The improved PSO differs from the conventional PSO by integrating the best components of different particles into the global best particle. This makes the structure no longer in all components but concentrated on the best particles, which makes the material used by the structure greatly reduced. In addition, unlike the method based on the finite element method, branch growth is based on a large number of FDM 3D printing experiments. The results show that the proposed modified PSO and its combination with the greedy strategy effectively reduce the volume of the tree support structure. Through comparative experiments, the results show that the proposed method outperforms the recent research results. The limitation of the study is that the proposed method needs to derive the yield length function of a series of key parameters (printing speed, layer thickness, material, etc.) on the branches, which requires a large number of printing experiments. Some programme need to be designed to obtain approximate results and save time and materials for printing experiments. However, the method has practical value for designers and manufacturers to save material and printing time, while the goal is to reduce the volume of internal support structures, it is also applicable to external support structures, and can be adapted to the design of tree support structures of other additive manufacturing technologies, such as SLA and SLM [9].

3D printers require support structures to connect the hanging part to the lower part of the object or the ground for printing. Optimizing the volume of the support structure can save material and printing time. Existing support generators are usually built into 3D printer software, but they produce support structures that are not sufficiently optimized and require additional material support.

A geometrically based approach was proposed to minimize the total length of the support structure by positioning the input 3D model to the location of the minimum area that requires support and then gradually building the support structure. The proposed method effectively supports all hanging parts by geometric optimization using tree-like supports, and takes into account printer and model printability.

The method was tested on a MakerBot Replicator 2 printer and its performance was compared with that of the printer's built-in software, as well as the Autodesk Meshmixer software. The results showed that the proposed method reduced the printing time by 29.4% and the material consumption by 40.5% on average. This method significantly saves material and printing time compared to the built-in Makerware software. Compared with Meshmixer software, the proposed method still reduced the printing time by 11.8% and the material consumption by 12.4%. The method was optimized for FDM printers because they are the most popular 3D printers on the market in terms of price and materials [10].

The 3D model's orientation in the context of 3D printing has a significant impact on properties such as mechanical strength, surface smoothness, printing time, and the amount of material required for the support structure. The support structure (S) is crucial for preventing parts of the model (M) from collapsing during the printing process; however, minimizing the volume of S is essential to conserve printing time and material. This study investigates the influence of M's orientation on the support structure's volume. An efficient algorithm, potentially utilizing GPU, has been developed to calculate the support volume for a given orientation. It is relatively faster and more accurate. The algorithm is employed to determine an orientation that minimizes the support volume for constructing the model. The support structure’s volume is a continuous but non-smooth function concerning orientation angles. The algorithm is proficient in identifying an orientation with a minimal support volume, often proving to be optimal in practical cases. Experimental results affirm the effectiveness of the approach, further enhancing our comprehension of the challenge of computing the support volume for a specific model orientation [11].

This paper addresses the time and material consumption involved in generating and removing auxiliary support structures in traditional 3D printing technology when manufacturing complex models. To solve this problem, a five-axis 3D printing algorithm based on model decomposition is proposed. In this algorithm, a spatial model is decomposed by layer cutting method, and a multi-fork decomposition tree with each node corresponding to each decomposition submodel is maintained during the decomposition process. Then, according to the structure of the multi-fork decomposition tree and the information of the corresponding tree nodes, the model printing path of the five-axis 3D printing device is planned. First, the model decomposition algorithm is carried out. This process includes: initial support region identification, layer cutting method and segmentation region identification, model segmentation and re-decomposition. Following this, the process includes decomposition tree and path planning, and finally, collision detection and replanning. Then the experiment results are obtained and analyzed. Finally, this paper identifies the inherent shortcomings of traditional 3D printing technology through a series of experiments based on data and models. The paper evaluates a variety of algorithms by applying them to the 3D model, comparing their decomposition outcomes, and ultimately achieving favorable results that validate the proposed method [12].

This paper introduces that the support structure must be added in fused deposition 3D printing under certain conditions, and puts forward the method of stripping the support structure from the printed part to better improve the removal of the support structure. The paper cites the necessity of adding support structures in fused deposition 3D printing for a detailed introduction. The types and generation methods of support structures formed by melt deposition are described, including the types of support structures and generation methods of support structures formed by melt deposition. Finally, the stripping methods and measures of the support structure were carried out. The paper first summarizes various methods for stripping the support structure, then details measures to facilitate easy removal, with experimental studies conducted to draw accurate conclusions.At the same time, a series of experimental studies are carried out in this process to get an accurate conclusion. If an ideal effect is wanted, optimizing the choice of parameters when the slices can be layered, the orientation of the model, the choice of supporting materials are needed. This will simplify the support structure [13].

3 Generation of Two Support Structures

The FDM process critically depends on the presence of a support structure. Without a support structure, the overhanging part will collapse, leading to print failure. An effective support structure should possess features such as adequate support, stability, easy removal, and minimal use of consumables. The generation of the support structure primarily involves two steps: identifying the areas requiring support and selecting the support structure, along with implementing the algorithm. Currently, there are two commonly used methods for determining the support position. The first method involves calculating the angle between the normal vector outside the triangular plane and the z-axis direction, while the second method involves slicing the model and performing Boolean operations to identify the support placement. The existing support structures include cylinder-shaped, grid-shaped, and tree-shaped designs, which serve as the basis for numerous software and research. This paper will briefly introduce two types of supports, namely cylinder-shaped and tree, to facilitate comparison with the support structures used in various software.

Cylinder-shaped support structure

The cylinder-shaped support is predominantly cylindrical, stretching from the print plane to the model support point. Cura utilizes the cylinder-shaped support as its support structure. Initially, it is vital to identify the point requiring support. The model presents three supported areas: the suspension surface, suspension line, and suspension point. These areas can be used to connect the support structures. The precise support point is determined using the aforementioned method to ascertain the support area.

Subsequently, the addition of a cylinder-shaped support perpendicular to the XOY plane at the support point is necessary. At times, the cylinder-shaped support structure may encounter situations requiring it to intersect with the model, as depicted in Figure 3. In such cases, the printing algorithm must be optimized to ensure the correct support is printed.

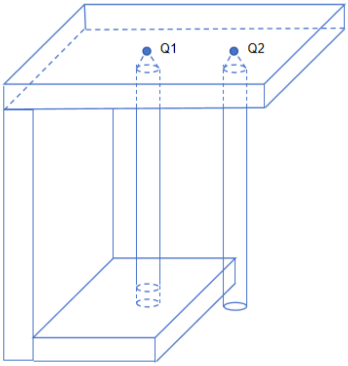

Fig. 3. Diagram of the cylinder-shaped support structure (Photo/Picture credit: Original)

The cylinder-shaped support structure represents a relatively straightforward support system that effectively addresses the adhesion issue between the model and the support structure. However, most cylinder-shaped structures are based on the platform. For more intricate model cylinder-shaped structures, additional cylinder-shape supports and materials are necessary, leading to potential material wastage. The tree support structure resolves the problem of excessive material consumption because of its more simply structure. Moreover, the contact surface between the tree support and the model itself is smaller, thereby enhancing model accuracy.

Meshmixer includes a tree support structure algorithm, and the acquisition of support points aligns with the cylinder-shaped structure. Nonetheless, the tree-shaped support structure belongs to hierarchical support, as illustrated in Figure 4. The support points generate branches downward, and the intersection extend downward as new support points. Ultimately, the tree trunk connects to the printing platform. While this design is at the core of material conservation, it also gives rise to stability issues for the tree support.

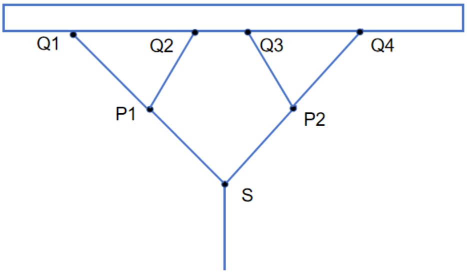

Fig. 4. Diagram of the tree-shaped support structure (Photo/Picture credit: Original)

4 Generation of Support Structures in Different Software

This paper utilizes the files provided by the software, such as bunny.stl in Figure 5, to create the model. The support structure generation and simulation are executed in separate software using the same parameter settings for critical angle, sampling point screening, resulting in various types of support structures. The key data of interest include the support material usage, support material removal difficulty, time for support structure generation, and calculation time for the support point screening algorithm.

The software tested in this study are Cura, Meshmixer, and Slic3r, known for their simple interface and user-friendly operation. These software packages feature support structure algorithms and are beginner-friendly. Additionally, the China Zhejiang Flash casting technology's professional slicing software, flashprint, is also evaluated for its concise interface and user-friendliness.

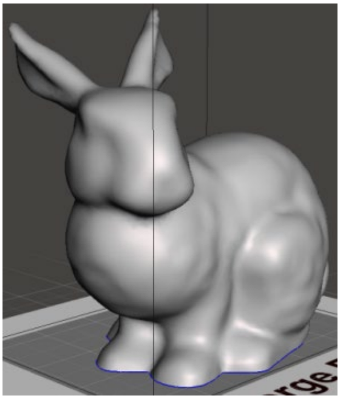

Fig. 5. Bunny.stl (Photo/Picture credit: Original)

5 Results and Discussion

5.1 Support Structure in Cura

As illustrated in Figure 6, Cura features both cylindrical and tree-shaped support structures. Table 1 demonstrates that the tree-shaped support structure conserves printing materials and almost doubles the printing time. The cylinder-shaped support structure generated by Cura exhibits impressive stability and strength, effectively providing support. However, this structure has a high contact density with the model, as evidenced in Figure 7. Removing the support structure is extremely challenging and results in significant material wastage during the printing process

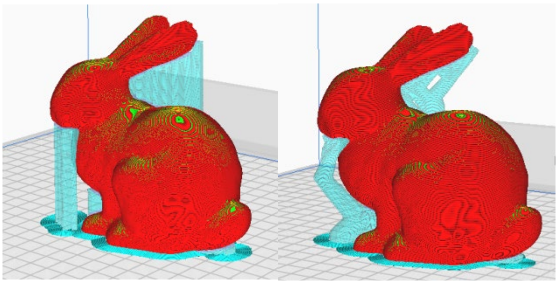

Fig. 6. Bunny.stl Cura cylinder and tree support diagrams (Photo/Picture credit: Original)

Table 1. Printing time and material required for the two supports(Cura)

Support type	Print time	Material amount
Cylinder	1h9min	14.4g
Tree	1h	13.2g

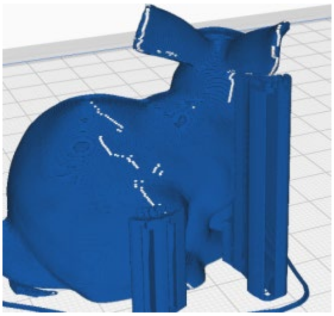

Fig. 7. Local magnification of the contact site between the model and the support (Photo/Picture credit: Original)

5.2 Support Structure in Slic3r

Figure 8 demonstrates that Slic3r's support structure is highly stable and adequately supports suspended parts. However, this also implies that Slic3r may result in material wastage when printing simpler models. This software may be more suitable for printing intricate models, such as hanging structures, due to its increased use of support materials.

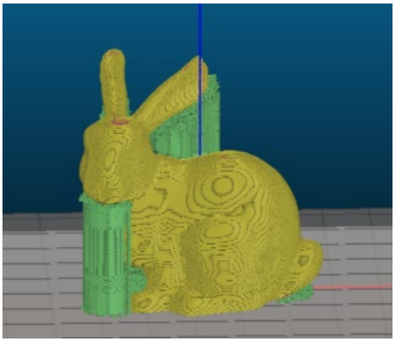

Fig. 8. Bunny.stl Slic3r cylinder support diagram (Photo/Picture credit: Original)

As shown in Figure 9, the support structure of Slic3r has a large contact area with the model, which means that the removal of the support structure will be difficult.

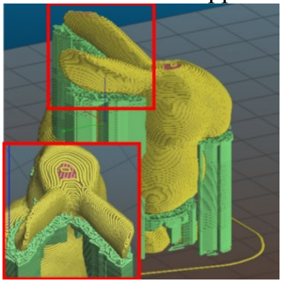

Fig. 9. Local magnification of the contact site between the model and the support (Photo/Picture credit: Original)

5.3 Support Structure in Meshmixer

Meshmixer uses internal Overhangs modules to construct the support structure. The resulting tree support structure is uncomplicated and easily removable, as shown in Figure 10. However, due to the relatively small contact area of this support structure, more forces are applied, which may lead to model deformation at the contact between the model and the support. Moreover, the software algorithm's complexity is higher, and it demands superior hardware. As depicted in Figure 11, Meshmixer generates the tree support structure. There are several approaches for addressing the issue of software support structure. Enhancing the algorithm enhances both the generation time and the strength of the structure. For instance, the novel tree support algorithm detailed in literature and the utilization of the L-system algorithm can facilitate a range of support structures with strong stability [14].

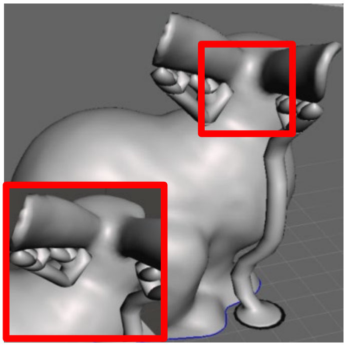

Fig. 10. Local magnification of the contact site between the model and the support (Photo/Picture credit: Original)

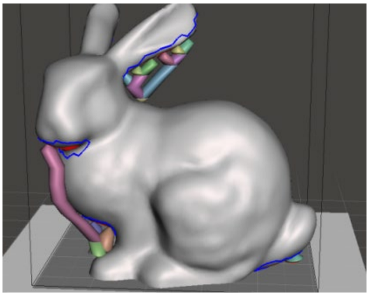

Fig. 11. Bunny.stl Meshmixer tree support diagram (Photo/Picture credit: Original)

5.4 Support Structure in Flashprint

As shown in Figure 12, the support structure of Flashprint is similar to that of Cura, both of which have two support structures: cylinder support and tree support. In Figure 13, it is clear that the contact between the supports and the models is less than Cura, which means it is easier to move out the support structure.

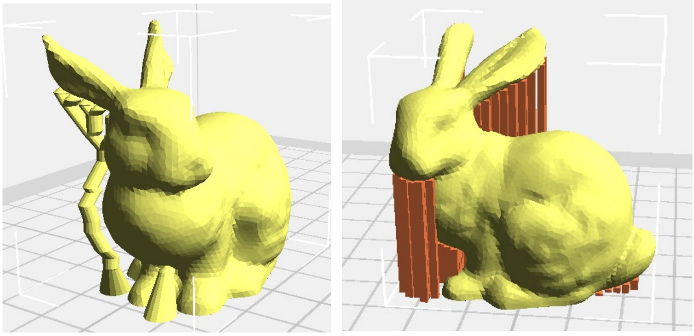

Fig. 12. Bunny.stl Flashprint cylinder and tree support diagrams (Photo/Picture credit: Original)

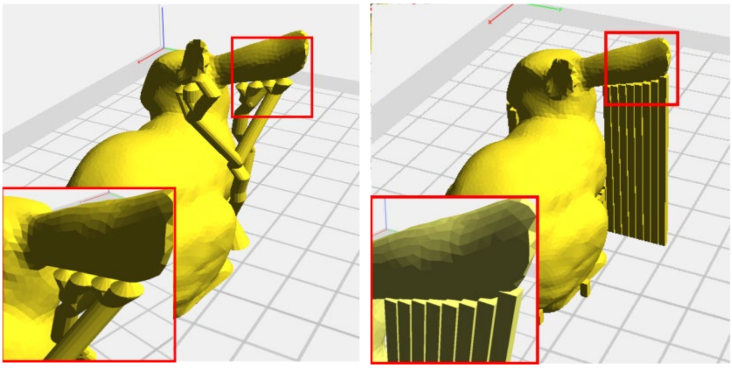

Fig. 13. Local magnification of the contact site between the model and the support (Photo/Picture credit: Original)

From Table 2, it can be known that the situation is similar to Cura, tree support structure saves time and material. Flashprint also saves more than Cura does, but it is not always like that, the parameter can be changed so that it can't be sure which software of these two is better.

Table 2. Printing time and material required for the two supports(Flashprint)

Support type	Print time	Material amount
Cylinder	1h7min	12.6g
Tree	1h5min	12.4g

5.5 The Slicing Speed of the Two Software

Cura and Flashprint are similar in some ways, so in this study ,this study focuses on the running speed of these two software. Using the same computer and the same model, this study records the slicing running time for two kinds of support structures, tree and cylinder. From Table 3, it is found that the running time of Flashprint is shorter, which means it has a faster algorithm.

Table 3. Comparison of the operation speed of the two slicing software

Software	Running time(tree)	Running time(cylinder)
Cura	6.61s	6.01s
Flashprint	5.60s	5.23s

6 Conclusion

After evaluating several representative software programs, it is found that those classic non-Chinese software applications possess the advantages of simple operation and strong practicability. For column and tree support structures, the use of these three software programs can generally meet most printing requirements. However, they also have their own deficiencies, such as the excessive support structure in Slic3r leading to material waste, the inability to set in detail in Cura, and the tendency of Meshmixer's support structure to deform the model.

As for the Chinese software Flashprint, it not only has the advantages of other software, allowing it to meet many basic and advanced requirements, but it also operates more concisely, is easier to use, and can be compatible with various models in actual application scenarios.

Through the comparison of these software programs, it is known that different software should be used according to different needs in practical applications, and these software still have room for improvement. It is hoped that more effective software will be developed in the future to meet the needs of scientific research.

This study would like to see how the developments in software programs related to printing support structures have further advanced since then. The ability of these programs to address deficiencies such as material waste, detailed support structure settings, and model deformation is crucial for practical applications. Moreover, the conciseness and compatibility with various models offered by Flashprint seem quite promising for scientific research needs. It's evident that there are still opportunities for enhancements in these software solutions – looking forward to witnessing future advancements in this domain.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

1. ASTM International: F2792-12a standard terminology for additive manufacturing technologies. ASTM International, Pennsylvania (2009).
2. Zhang, X.J., Tang, S.Y., Zhao, H.Y., et al.: Research status and key technologies of 3D printing technology. Materials Engineering 44(2), 122-128 (2016).
3. He, X., Pan, X.: Research on Automatic Support Generation Technology in FDM Process. Machine Tool & Hydraulics (4), 37-40 (2012).
4. Yang, J.: Effect of surface inclination angle of parts on supporting parameters of MEM process. Mechanical Engineer (5), 84-86 (2006).
5. Yang, Y., Fuh, J.Y.H.: Multi-orientational deposition to minimize support in the layered manufacturing process. Journal of Manufacturing Systems 22(2), 116-129 (2003).
6. Hao, X.: Research on metal 3D printing Control System Based on FDM Technology. Chongqing Three Gorges College (2024).

7. Shi, X.: Research Technology of support design rules in FDM. New Management 30(5), 663-665, 668 (2009).
8. Li, Y.: Research on Control System of Fused Deposition 3D Printer and Optimization of Process Parameters. Hebei University of Technology (2022).
9. Zhu, L., Feng, R., Li, X., Xi, J., Wei, X.: Design of lightweight tree-shaped internal support structures for 3D printed shell models. Rapid Prototyping Journal 25(9), 1552-1564 (2019).
10. Vanek, J., Galicia, J.A.G., Benes, B.: Clever Support: Efficient Support Structure Generation for Digital Fabrication. Computer Graphics Forum 33(5), 117-125 (2014).
11. Ezair, B., Massarwi, F., Elber, G.: Orientation analysis of 3D objects toward minimal support volume in 3D-printing. Computers & Graphics 51, 117-124 (2015).
12. Wang, Z., Zhao, D.: Research on support reduction algorithm for FDM 5-axis 3D printing. Mechanical Science and Technology (10), 1673-1677 (2023).
13. Lu, S., Chao, Y.: Research on support structure and easy stripping method of FDM 3D printing. Science and Technology Innovation and Application (09), 122-123 (2019).
14. Song, G.-h., Jing, S.-K., Xu, W.-t., Liu, J.-H., Yang, H.-c.: Design method of tree support structure generation for fused deposition molding. Computer Integrated Manufacturing Systems 22(No.3), 583 (2016).