# Survey on Optimization of Support Structures in 3D Printing

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**Abstract.** When manufacturing complex parts using 3D printing technology, support structures are crucial for ensuring build quality. However, their use also leads to issues such as material waste, increased costs, and cumbersome post-processing. This paper synthesizes innovations and optimizations in support structures from various researchers. These optimizations have become key to enhancing printing efficiency and sustainability. Traditional methods of manually or automatically generating supports via software often suffer from limitations like inefficiency or material redundancy. This paper evaluates that these optimization strategies enhance the economic efficiency, quality, and functional reliability of support structures. While there remains room for improvement in handling complex structures, they collectively advance 3D printing toward greater efficiency, precision, and environmental sustainability.

**Keywords:** 3D Printing, Optimization of supporting structure, topological optimization, Multi-axis printing, Bionic tree-like structure

## 1 Introduction

3D printing operates on the fundamental principles of segmentation and layering. Using computer software such as CAD, a three-dimensional model of the part is created. Slicing software then processes this three-dimensional image—with length, width, and height—into countless layers of thin slices with only length and width. Specialized materials are then used by the printer's nozzle or laser beam to build up these layers sequentially, forming a physical object in reality [1]. To produce a wide variety of complex parts, the printing process must simultaneously construct a vast number of support structures.

In traditional 3D printing, all support structures are typically generated automatically through preset methods in the printer or printing software. This often results in significant material waste, as these parts frequently require far more support structures than necessary. This approach is cost-inefficient and exacerbates environmental damage [2].

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For special parts with high technical requirements, ensuring their precision also necessitates meticulously removing the support structures after printing. This process may impact the fineness of the component itself [3].

This paper examines existing optimization approaches and finds that structural optimization of support structures primarily focuses on two objectives: reducing material consumption while maintaining strength. This encompasses both structural optimization of the support framework and optimized design of the printing process. By optimizing the structure of support structures, it is evident that emissions of gases affecting the atmosphere or environment can be reduced, costs can be optimized, and the surface quality and smoothness of parts after support removal can be improved. This prevents quality defects from compromising part strength.

## 2 Traditional support structure model

When layering a model, the slicing engine calculates and creates support structures not present in the original model based on preset parameters to assist in model formation.

Traditional support structures are generated primarily through two methods. One requires designers to manually add support structures within modeling software, while the other relies on slicing software employing its own algorithms to automatically generate support structures [4].

For manual support addition, modelers perform manual operations within CAD software to construct 3D models, adding support structures to assist in printing. This process requires operators to possess advanced technical skills and is relatively inefficient [4].

Software such as Cura or MeshMixer automatically generates support structures based on preset algorithms tailored to the model's requirements. These preset algorithms offer limited configurable parameters and lack sufficient flexibility or freedom, potentially resulting in overly complex support structures that waste material and printing time [4].

## 3 Octagonal prism-shaped support structure

The octagonal prismatic support structure is an optimized variant of the prismatic support structure (as shown in Figure 1) [4].

The support structure with eight sides provides a form that appears similar to a form with sides forming a complete round shape for each level in the process of forming the model. This particular structure shows reduced use of material and also shows that variation in motor operation remains at a lower level in the process. The result indicates that time for forming the model decreases in a significant manner. The structure with eight sides that provides support receives processing using a method that samples, following analysis of grouping in space. This processing allows the structure to provide a space for forming that shows stability and also allows the structure to provide dissipation of heat that shows effectiveness. These features of the structure indicate that deformation of the model decreases and also indicate that precision of the model increases. The structure with eight sides that provides support shows difference from structures that provide support following approaches that appear more common in practice.

The difference relates to the extent of the contact area between the structure and the solid model. The structure shows a contact area that appears smaller in extent. This feature indicates that removal of the structure occurs with greater ease in comparison to removal of other structures [4].

The limitations of support structures using an octagonal prism form show clear patterns in the data. The performance of these structures depends on particular parameter values that require consideration. The measure of the circle surrounding the structure relates to both stability features and material use in the process. When this measure shows small values, the support structure indicates insufficient stability and the structure appears likely to fail during the process of printing. When the measure shows large values, the structure requires more material and the process requires more time for completion. The octagonal prism approach also shows different performance across model types that appear in practice. For simple model forms, these support structures demonstrate strong performance in the data. For complex model forms, the structures show limited performance in findings. Models that include features extending outward in spherical forms provide an exam.

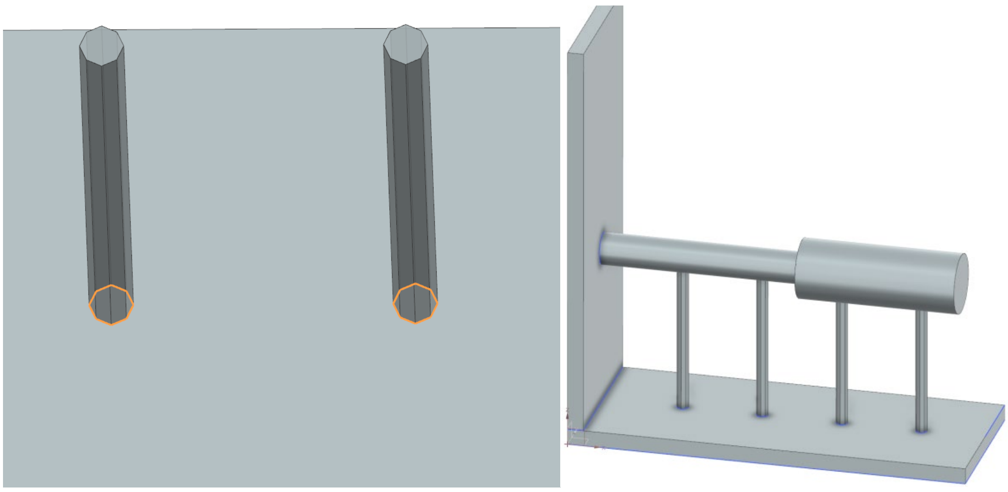

**Fig. 1.** Octagonal Prism Structure[4].

## 4 Topological optimization for support structure

Topology optimization provides a method to establish the distribution of material that shows the best performance under conditions that limit design. This approach allows the development of structures that contain less material and show increased strength for use in printing with three dimensions.

The method shows high effectiveness in different cases. One particular case involves printing structures that contain many small openings and that require extensive additional material during printing to provide support. These support structures present difficulties for removal and require considerable time and work to address. The approach using density as the main factor in topology optimization examines the design space to find the distribution of material that provides the best results. The main aim involves reducing the total change in form that occurs under conditions of use while also meeting requirements that limit the volume of material. The optimization includes the use of filtering methods that ensure the structure provides its own support during printing and that ensure dimensions remain within acceptable ranges. These filtering approaches ensure that the structure allows manufacturing using available methods. For cases that involve the same volume of material, this approach shows performance that differs significantly from performance that results from using traditional structures with uniform patterns of small openings or from using methods that simplify existing designs in a direct manner. The results indicate advantages in multiple aspects of performance [5].

The approach of using WAAM provides a method for producing components from metal that apply an optimization process for structure design. This process works to improve elements that provide support or connection in the structure. The approach allows developing parts that show reduced mass but maintain high levels of performance. The optimization process that focuses on structure form operates by removing regions in the material that do not experience significant load. It also replaces sections that appear as continuous flat elements with arrangements of connected supporting members. This allows reducing the total mass of material in the component. The process also works to distribute material in ways that meet requirements for resistance to deformation. The distribution of material follows patterns that indicate optimal placement for supporting applied loads. This approach shows particular value in sections of the structure that provide support functions. The optimization reduces the amount of material required in these sections. The result shows that(As shown in Figure 2) [6].

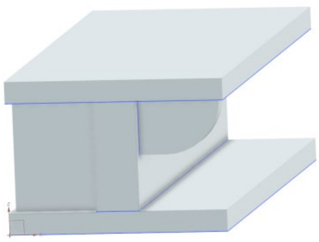

**Fig. 2** uses truss structures instead of the reinforcing bars of the solid plates

## 5 Multi-axis printed optimize self-supporting of structure

By utilizing multi-axis printing to maximize the self-supporting properties of printed objects, this is an optimized approach that combines structural optimization with multi-axis 3D printing path planning [7]. First, identify the ideal print surface for the optimized structure, then secure the entire assembly while simultaneously refining both the structure and its print surface. This enhances structural performance and minimizes overhanging components. While ensuring mechanical integrity, this approach maximizes structural self-support to reduce support material usage. By optimizing through zoning and localized print orientation, it fully leverages the flexibility of multi-axis printing to expand directly printable areas. Compared to traditional three-axis methods, it achieves superior structural performance with minimal increase in material volume (as shown in Figure 3) [7]. During the printing process, however, changes in the platform angle for certain complex components may cause the print head to bump against the part, resulting in minor surface defects.

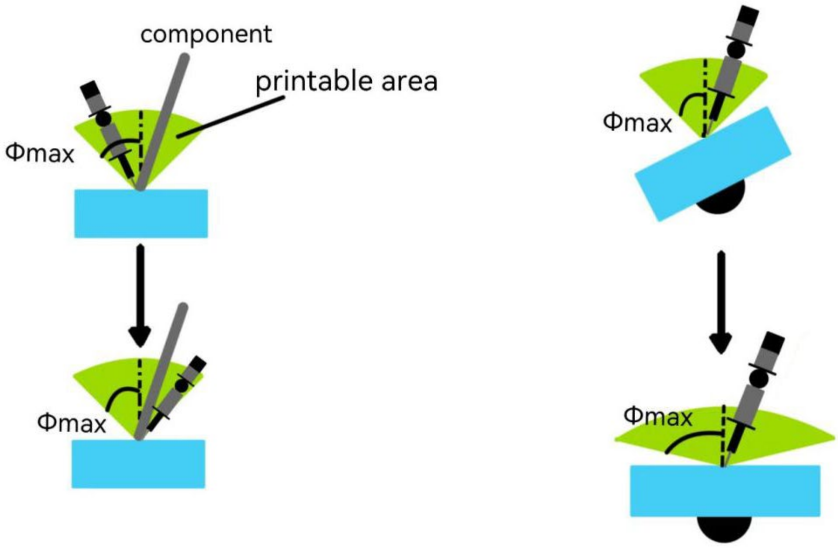


**Fig. 3.** Three-axis printing and multi-axis printing [7].

## 6 Bio-inspired supporting structure

Bionic tree-like structure optimization represents an innovative approach in the design of 3D-printed support structures (as shown in Figure 4) [8]. By simulating the growth patterns of trees in nature, generate efficient and eco-friendly support structures to reduce material consumption and enhance print quality [8].

Starting from the print baseplate, generate a grid. Then vertically project the grid points onto the surface of the model to be supported, forming support contact points. Finally, using an umbrella search algorithm or a similar fractal-based method, tree-like branches are iteratively generated downward from the support contact points. At each branch point, support lines are generated from surface points toward the base plate by grouping support points. Overlapping support lines are then iteratively reduced, ultimately forming a hierarchical structure of trunks and branches. This ensures branch angles do not exceed the droop angle.

However, the Z-buffer algorithm for tree generation requires multiple computations of numerous intersection points, inevitably increasing preprocessing time. Consequently, computational efficiency must be optimized [8]. Moreover, this method performs better on cage-like structures, while its support capability for free-form printing remains to be improved [2].

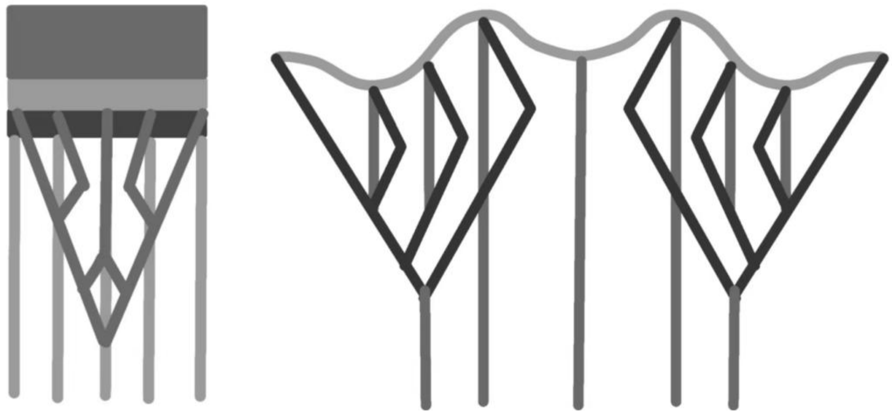

**Fig. 4.** Tree-like Structure Diagram [8].

## 7 Performance Evaluation and Efficiency Analysis

Performance evaluations for supporting structure optimization are typically multidimensional.

Economic and efficiency metrics serve as the most direct evaluation criteria, encompassing material consumption for the support structure itself, the total printing time extended by adding supports, and the labor and time costs required to remove supports during post-processing. In this regard, biomimetic dendritic structure optimization and topology optimization demonstrate certain advantages by achieving significant material savings [2][5]. Therefore, such solutions are particularly suitable for scenarios requiring high-volume printing while controlling printing costs. They are ideal for direct digital manufacturing of consumer goods.

Print quality metrics refer to whether the quality of printed components can be guaranteed. Therefore, the evaluation includes the impact on model dimensional accuracy and geometric fidelity, as well as the surface finish or roughness of the model after support removal. In this regard, biomimetic tree-like structure optimization also holds advantages [2]. Suitable for manufacturing structures in aerospace applications where precise aerodynamic performance is required, or for use in artistic creation.

Measures relating to function and reliability mainly involve the strength and stability of structures that provide support in the process of printing. These measures focus on the manner in which these structures resist the effects of heat and prevent the model from changing form or experiencing collapse. In this particular context, structures that show the form of octagonal prisms provide considerable benefits for models that present limited features. These structures allow heat to move away from the model at a high rate. This process reduces changes in form that occur during printing. The reduction in such changes also produces improvements in the level of precision that the model demonstrates [4]. Such stability and reliability often make them the preferred choice for large structures or fundamental industrial components.

The main advantage of the approach using multiple printing directions is that it provides movement across different orientations. This process involves changing the direction of printing as the structure develops. The method allows sections that extend outward to remain at positions that the process can produce without additional supports. This reduces the requirement for support structures in a significant way. The approach minimizes reliance on these structures or removes the requirement entirely. The primary use of this method occurs in conditions without significant force from the pull that Earth provides [7]. These conditions exist in locations beyond Earth. The method allows printing operations in these particular environments.

## 8 Deficiency and Prospect

The distinct advantages of 3D printing have simplified the design and manufacturing of personalized crafts and components, while simultaneously introducing numerous new challenges in component printing and fabrication, thereby driving research in related fields [9].

Despite the significant achievements in current optimization methods for supporting structures, it has been found that existing research still exhibits several common limitations and shortcomings.

The advantages of various optimization methods are highly dependent on specific application scenarios. Octagonal prism structures exhibit good stability in simple models but perform poorly when dealing with complex cantilever structures [4]. Bionic tree-like structures demonstrate exceptional efficiency in handling cage-like models, but their support capabilities for free-form objects remain inadequate [2]. The findings suggest that no general approach to making processes better can work across different forms of printed structures in three dimensions. Methods that use printing along multiple directions show important possible benefits for reducing the need for support elements, but these methods also present different problems that require solutions. Changes in the direction used during the process can produce defects on the surface of the parts that result. Maintaining surface features that remain consistent when printing involves high levels of movement freedom represents a main challenge for current research in this area [7].

This work considers these limitations and suggests that study on improving support structures in printing using three dimensions may show increased focus on combining systems that allow learning from data with various approaches to support design. The main goal involves developing systems that show intelligence in selecting or producing optimal support solutions using model form, material features, and performance requirements. This allows intelligent and flexible improvement. A different approach involves combining optimization methods in substantial ways. The approach may combine principles from structure optimization that reduce material with efficient force patterns from structures found in nature. Another possibility involves applying units that support themselves from structure optimization within printing systems using multiple directions. This uses the particular strengths that each method provides. The overall goal involves achieving complete optimization of current support structure development in this type of printing [10].

## 9 Conclusion

This study examines different approaches for developing support structures in the process of printing in three dimensions. The analysis considers structures that use octagonal forms in prismatic design, methods that involve optimizing the arrangement of material, approaches that allow printing across multiple directions, and designs that follow patterns found in natural branching systems. The study assesses these approaches in relation to factors that include material use efficiency, quality of printed output, and performance in actual use. Findings from this work indicate that these approaches show significant effects in reducing the amount of material that is required, decreasing the difficulty of work that follows the initial printing, and improving the precision of models that are produced. These results suggest important implications for development in this area of printing technology.

The study also reveals that approaches that are currently available show particular limitations in application. These methods show high dependence on the specific context in which they are applied. The approaches that are examined do not demonstrate applicability across different situations. This limitation indicates that current methods do not provide optimization that extends to all aspects of the printing process. The analysis suggests that development in this industry will move these approaches toward greater use of intelligence in operation and toward integration of different methods. Printers that are developed in the future may include systems that use artificial intelligence. These systems could integrate supports that use octagonal prismatic forms, supports that follow dendritic patterns, and other forms of support structures that are examined in this work.

The approach using features of form to find structure will provide the main process for selecting the method that produces structures for support in the particular way that shows the most important outcomes. In conditions where individuals work in structures in space, the approach that uses multiple directions for the process will allow individuals working in space to conduct the work that these conditions require. The area that contains the methods for producing structures in three forms shows development that follows a pattern. This pattern appears as a form that increases in a way that occurs in stages that also show features of cycles. The changes that the area shows in stages relate to the process where approaches develop through changes in method and changes that occur when forms of the method that contain improvements appear. The use of the approach in the work that relates to space and the work that relates to structures for use by the state will show that the state provides the main role for the process where these changes that the method shows occur in stages in the work that uses this approach.

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