Biomimetic Form-Finding Study of Bone Needle Microstructure Based on Sponge Regeneration Behavior

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Abstract. The concept of "nature-algorithm-structure" refers to a digital design method in architecture that draws inspiration from nature, extracting its mathematical and physical conceptual models to construct structural systems with parameters. This study aims to address the challenge of parametric form-finding in reticular tension structures. By observing the phenomenon of "sponge regeneration", we further illustrate the generation and optimization of reticular tension structures through the hierarchical structures of "monomer"-"path"-"mesh". Tensile structural systems are rebound forms, and their analytical models must account for their nonlinear characteristics and the existence of equilibrium self-course. Starting from the growth dynamics of "sponge regeneration behavior", this paper extracts the logic behind it: sponge monomers combine randomly into partial units under the condition of shredding and discrete, forming a single organism through aggregation. The multi-dimensional bone needle serves as a structural component, enabling multi-axis reorganization, while the multi-directional mesh surface as a morphological component realizes multi-branch reproduction, forming a natural "network tension structure". This study focuses on the biomimetic form-finding of bone needle microstructure, drawing inspiration from sponge regeneration behavior. By analyzing the growth dynamics of sponge regeneration, we aim to develop a better understanding of the principles behind the formation of bone needle microstructure. This finding provides significant reference for the development of modern structures and promotes the bioshape and optimization of tensile structures.

Keywords: Sponge regeneration · Microstructure bionics · Reticular tension structure · Parametric form-finding · Finite element analysis

1 Introduction

Sponges are primitive multicellular organisms known for their strong regenerative abilities. Even from scattered fragments or single cells, a sponge organism can divide and regenerate to form a new adult sponge, which continues to grow. Researchers at the University of Ulster in Northern Ireland conducted experiments on the regenerative ability of sponges. They observed that fragmented sponge cells gathered and grew under the

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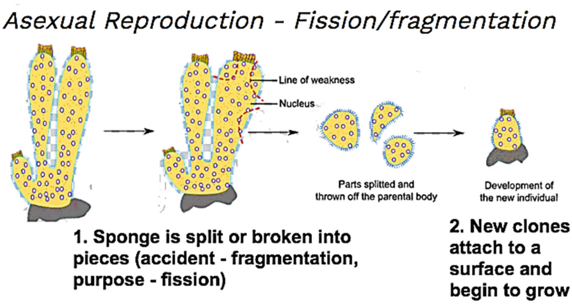
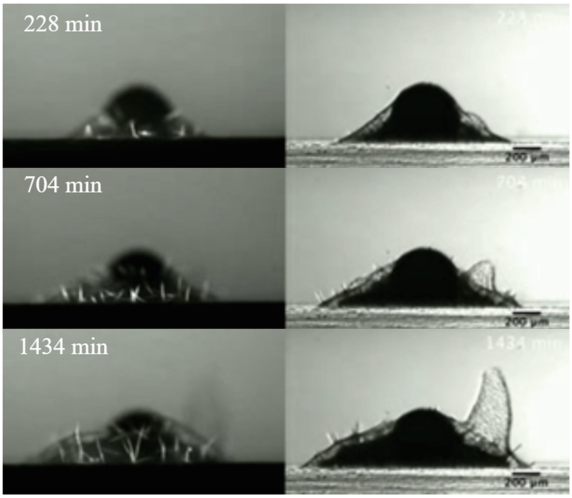
action of “aggregation factors”. The growth of sponges was monitored at three time nodes—8 min, 704 min, and 1208 min, see Fig. 1. Sponge regeneration and growth behavior. As bone needles supporting the monomer of the structure, the sponge cells formed a tensile overall structure of different shapes through the path of discrete polymerization. This resulted in the arrangement of fine holes for predation and cloaca on the side of the sponge structure [1]. Observing the regeneration behavior of sponges, and studying the basic monomers, polymerization paths, and reticulated epidermis, provides valuable guidance for biomimetic form-finding of building structures.



a) Sponge regeneration



b) Sponge growth process

Fig. 1. Sponge regeneration and growth behavior

The 1957 exhibition of the Federal Garden in Cologne was presented by Frei A concentrated exhibition of prestressed tents designed and built by Otto. In this exhibition, the earliest and most important forms of tensile film were established. This series of membrane structures has the characteristics of light weight, large span, flexible disassembly and installation, etc., which initially reflect the sustainable and vigorous vitality of this building type. Since then, Frey · Otto gained fame and began to have the opportunity to apply flexible membrane structures to public buildings with larger spans and longer lifespans. The modules of the Underwood pavilion evolved from different variants of the 3-pillar tension module, see Fig. 2. Tensile Structure classification. Changing the distance between the upper and lower surfaces of the module and changing the scale between the upper and lower surfaces of the module inform the curvature of the envelope. These changes also create different rotations within each module, causing the envelope to twist in different directions. The structural simulation engine rhinoceros film and kangaroo are essential tools in the process of finding the shape of the pavilion's structure. Compared with other structural systems, tension structures have great advantages. They mainly use tensile members and are lighter and stronger than conventional systems. The tensile structure is gradually extracted from the three elements of "bar", "cable" and "membrane", and Munich Olympic Stadium and BUGA Fibre Pavilion are the typical cases of "cable-membrane" structure; At the same time, the "bar-cable" tension structure came into being, such as Snelson's "Fly" series, Frumar et al.

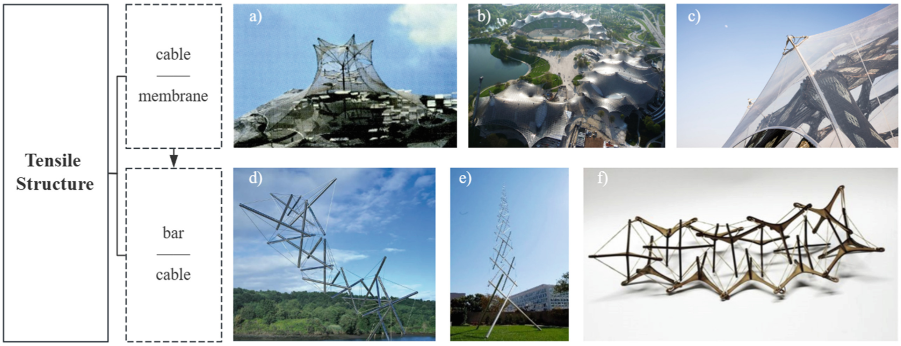


Fig. 2. Tensile Structure classification

Tension, tension integrity, or floating compression is a structural principle based on a system of isolated components pressed within a continuous tension network, arranged so that compression members (usually rods or pillars) do not touch each other and prestressed tensile members (usually cables or tendons) spatially depict the system. Because the members are loaded with pure compression or pure tension, the structure will fail only if the cable yields or the rod bends. This enables each member's material qualities and cross-sectional geometry to be tailored based on the precise load it carries. Because of these patterns, no structural parts experience bending moments, and the system has no shear stresses. This can lead to an exceptional situation.

Architectural biomimetics is a realistic way for guiding human construction operations by the natural world. Sponge growth and regeneration, monomer change, route derivation, and epidermal shape all have significant research implications for the formation of architectural structure. The modern tensile monolithic structure's main body is composed of rod, line, and surface, and its different morphological unfolding has different mechanical properties, and this paper extends the possibility of parametric form-finding of tensile structure by simulating the regeneration mode of sponge.

2 Method

The sponge monomer is discovered to have a fractal phenomenon, the path exhibits a discrete polymerization algorithm, and the environmental performance of the epidermis morphology is simulated to obtain the ideal form-finding condition, see Fig. 3. This study depicts sponge regeneration behavior from the four perspectives of observing the regeneration phenomenon-extracting the logic behind the extraction-constructing the microstructure system-force analysis, and the technical means are based on the Grasshopper platform, using the Rabbit plugin for monomeric fractal construction, the Waso plug-in for discrete aggregation path deduction, and Lunchbox + WeaverBird for mesh epidermal subdivision, see Fig. 4.

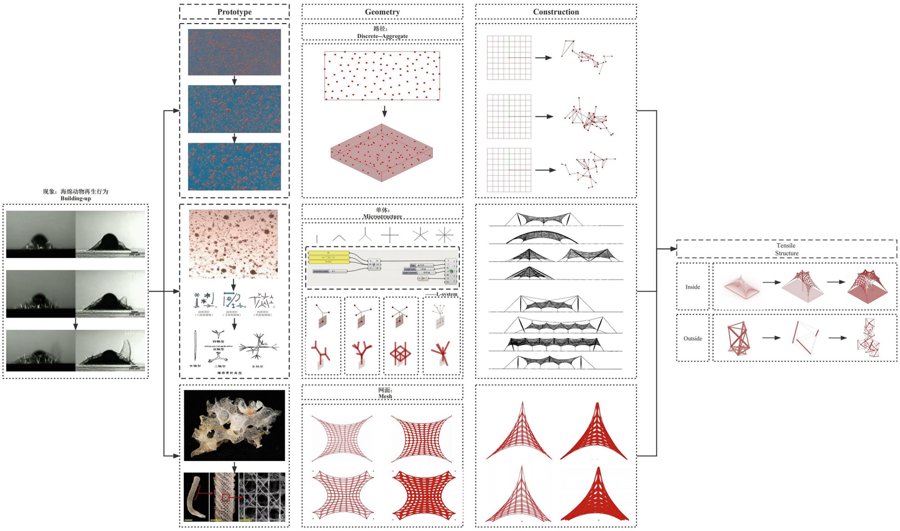


Fig. 3. Three paths coordinate

2.1 Monolithic Composition

The sponge is supported by a needle-like “skeleton”. The needle keeps the pores open and maintains the shape of a sponge [2], and can be divided into siliceous bone needles and calcium bone needles according to the type of bone needle material, see Table 1. Multiaxial bone needles; According to the number of axes, it can be divided into single-axis, double-axis, multi-axis bone needles; On that basis, it could be discussed.

The use of a fractal algorithm to expand the basic unit into several dimensions by specifying the initial value, iteration rules, offset angle, and bone needle monomers, see Table 2. Bone needle fractal algorithm. In the middle of the 1970s, a new area of modern mathematics called fractal arithmetic emerged refers to things that are self-similar in terms of phenomena, pictures, or physical processes. Mountains and trees

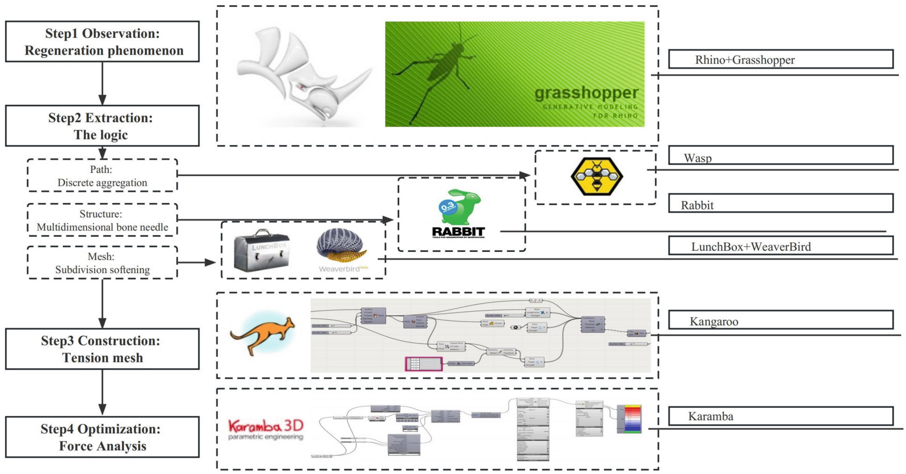


Fig. 4. Technical means

Table 1. Multiaxial bone needles

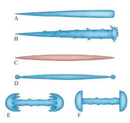
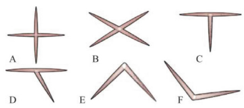
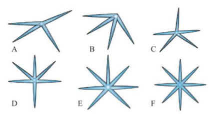
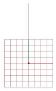
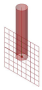
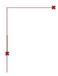
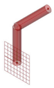
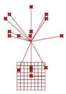
Uniaxial bone needle	Biaxial bone needle	Multiaxial bone needles
		

exhibit fractal phenomena in nature, and the creation of a mathematical fractal is based on an equation that iterates continuously, or a recursive feedback system. Mandelbro invented fractal geometry in his well-known book “Fractal Geometry of Nature,” where fractal algorithms are combined with ideas like chaos and tubers to form complexity science and direct the structure of the mathematical universe.

2.2 Path Derivation

The aggregation pattern of bone needles was observed under the microscope, and several bone needles were distributed in scattered points [3], and the center point of aggregation was selected and discretely polymerized with adjacent bone needles within the radius. The path generation is analyzed from the three angles of “boundary”—“plane”—“three-dimensional”, see Table 3. Discrete aggregation. In the boundary magnetic field effect, the magnetic field attraction effect is compiled with green, yellow and red, and the tensile structure monomer is compared with the group formation form, which is divided into four basic units of tension: monomer forward, monomer reverse, group monomer built-in, and group monomer extracorporeal composition. On the basis of this division, two tensile structural forms, built-in “cable-membrane” and externalized “bar-cable”, are

Table 2. Bone needle fractal algorithm

Step:10 Length Scale:1			
Type	2D	3D	Algorithm
Uniaxial			Axiom: FA Production Rules: B = &FAJ A = !""[B] Number of generations: 1 Angle: 90
Biaxial			Axiom: FA Production Rules: B = &FAJ A = !""[B] Number of generations: 2 Angle: 90
Multiaxia			Axiom: FA Production Rules: B = &AJ A = [!""[B]///[B]]FJ Number of generations: 7 Angle: 72

derived, and under the joint control of tension and tensile force, the monomer follows the discrete polymerization path to generate a group morphology.

2.3 Epidermal Morphology

Sponge animal skin presents a light lattice, which has high strength, light texture and good tensile performance, selects 150 * 250 m plane as the basic grid, the vertex of the structure is set at the center point, subdivides and softens it respectively, takes the local climate of Xiamen, China as the site conditions, analyzes the real number of light on the winter solstice, and conducts simulation analysis through Ladybug software, see Fig. 5. Epidermal contrast, and finds that the maximum number of light on the winter solstice can be reached after softening treatment.

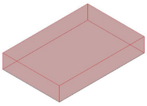
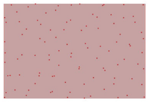
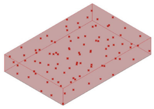
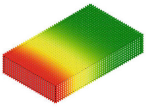
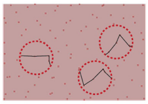
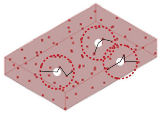
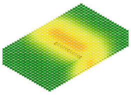
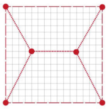
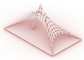
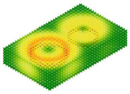
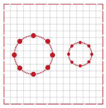
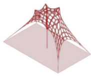
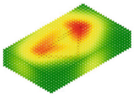
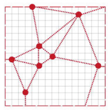
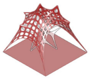
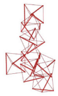
3 Structural Performance

3.1 Forward and Reverse Comparison of Monomers

On the basis of monomer research, the monomer morphology at N = 3 can be divided into two manifestations: built-in and externalized. Regarding the discussion on the built-in monomer, through the discrete aggregation algorithm, the magnetic field boundary conditions are set, the orbiting path is specified, different forms are generated, and the structure is found by digital means, see Table 4. Monomers are contrasted in different directions. Among them, in the composition of the built-in monomer, groups with different morphologies can be generated, and the groups can form the basic skeleton of the tension structure to create a variety of possible forms.

Compared with other traditional building structure systems, the new system with unique charm of the tensile integral structure is still "young", up to now, there is still

Table 3. Discrete aggregation

		Boundary	2D	3D	
Primitive					
Generation					
Optomization	Mono-mer				
		Positive			
					
		Negative			
	Group				
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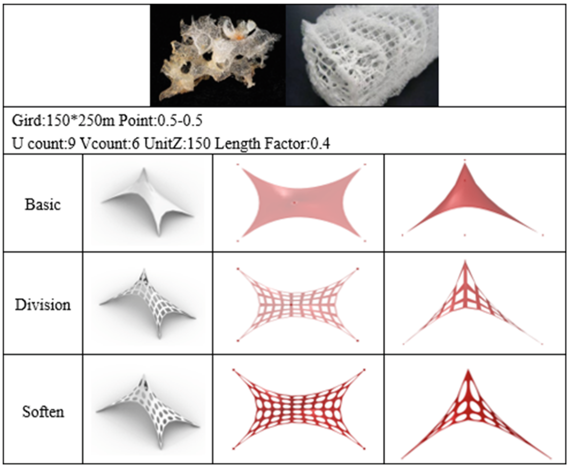
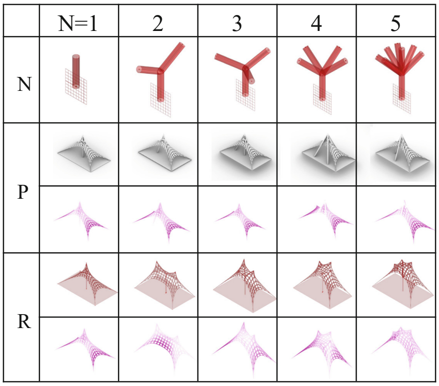
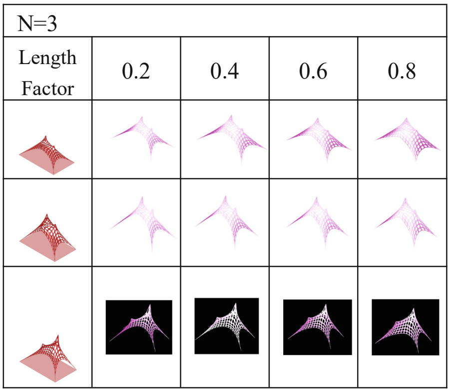


Fig. 5. Epidermal contrast

Table 4. Monomers are contrasted in different directions



a) Positive and reverse



b)Contrast of different heights

no real sense of tensile integral structural engineering works in the world, one of the significant reasons is that the tensile integral structure is a typical flexible structure [4], with the characteristics of large deformation and small strain, and the ability to bear the load is relatively low. The tensile membrane structure allows architects to design a variety of tensile self-balancing, complex and vivid spatial forms, which change with light throughout the day, and the sculptural membrane structure can take on different forms through light and shadow. At sunrise and sunset, light at low incidence angles will highlight the curvature and relief effect of the roof, and when the sun is at apogee, the streamlined boundary of the membrane structure is cast into the ground with a curved shadow, using the light transmission and reflection of the membrane, and the designed artificial light can also make the membrane structure a sculpture of light. The tensile membrane structure is not rigid and deforms under wind or snow loads. The membrane structure adapts to external loads by deformation, during which the radius of curvature of the membrane surface in the direction of the load is reduced until it can resist the load more effectively. The flexibility of the tensile structure allows it to produce large displacement without permanent deformation, the elastic properties and prestress level of the membrane material determine the deformation and reaction of the membrane structure, and the flexible characteristics of adapting to nature can inspire people's architectural design.

3.2 Group Discrete Aggregate Deduction

Fractal monomers are generated based on the "Rabbit" plug-in in the Grasshopper platform, and then a discrete aggregation algorithm is generated according to the "WASP" plug-in in the platform, see Table 5. Group discrete aggregation. The generation logic of its algorithm consists of four parts: unit-spatial adaptor-component-group. For the tensile membrane structure, take the 3-rod as an example to construct the structure: firstly, the straight rod of the 3-rod is multipiped to make the port, length and thickness of the member have nonlinear morphological changes; Secondly, an adaptor adapted to the space of 3 rods is established to realize the fit between surfaces and surfaces between different spatial adaptors, so that the members can move, rotate, mirror and other operations in the space adaptation. Furthermore, for path derivation, designers can limit the corresponding field conditions (regular, irregular) and path direction (linear, nonlinear); Finally, according to the above conditions, different forms of bone needle morphology are discretely aggregated, and different forms of tensile membrane structures are supported and extended.

Table 5. Group discrete aggregation

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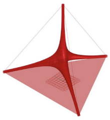
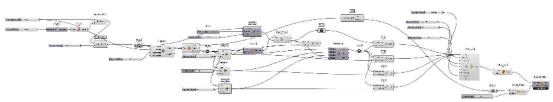
<tr><td></td><td colspan="2"></td></tr>
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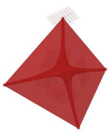
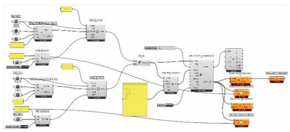
<tr><td></td><td colspan="2"></td></tr>
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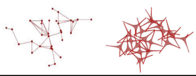
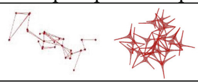
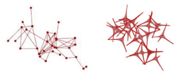
<tr><td></td><td></td><td></td></tr>
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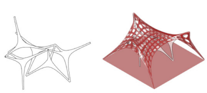
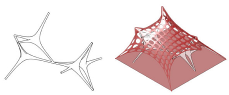
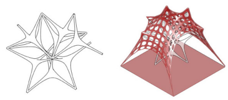
<tr><td></td><td></td><td></td></tr>
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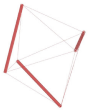
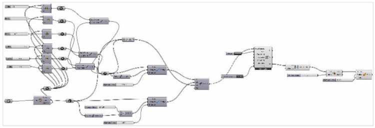
a) Groups are built-in

(*continued*)

Similarly, the “bar-cable” structural form is derived on the basis of the “cable-membrane” tension structure. The compression members of the composite tensile integral structure enhances the overall stiffness and stability of the structural system. The stiffness of the structure as a whole is no longer limited to the tension of the prestress, reducing the excess internal stress [5]. Continuous compression members can maintain an effective force flow path and improve structural efficiency. From a mechanical point of view, the continuous compression member reduces the steps of force flow transmission and the force transmission path becomes simpler. The simpler the force transfer path, the greater the structural efficiency. The continuous transmission of the pressure member can maintain the effective transmission of force flow, which greatly improves the structural efficiency. The structural structure is relatively simple, which reduces the difficulty of making stressed members and connecting nodes, and can realize on-site

Table 5. (*continued*)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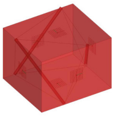	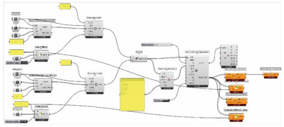	
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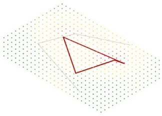	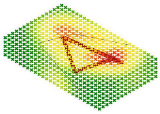	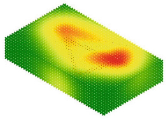
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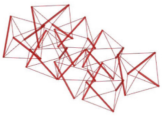	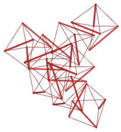	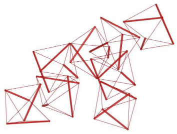
Step4 Discrete Clustering		

b) Group externalization

production and installation, which greatly reduces the size of the prestress, reduces the difficulty of construction, and makes the structural system easier to achieve.

4 Discussion

The tensile members are used to control the load or stabilize the junction of the whole Structural system, the cable is directly anchored to the rigid skeleton, directly controlling the skeleton, without the need for the action of the brace. Tensile members can be divided into two types according to the force action, one is common to the rigid skeleton system. Support cables for the self-weight (fixed load) of the support structure, and the other type assists the rigid skeleton against additional live loads. Stable cables to avoid deformation of the structural system; According to whether prestress is applied or not, it can also be divided into two types, one is pretension. Cables, the other is non-pre-tensioned cables. The main feature of this structure is the controlled loads, which are mainly used in contact with each other. The compressive members resist external or self-weight loads and are connected to each other by tensile members to enhance stiffness and stability.

Compared with the strut structure, the skeleton structure greatly reduces the amount of prestress to be applied during the construction process. The combination between the compression member and the tensile member is exquisite, making full use of the bearing capacity of the rigid skeleton structure, and the combination is stable [6]. The lightweight cable of the fixed control system enables the lightweight structure to produce high strength. The sponge skeleton further expands the tensile structure. The continuous development of science and technology has prompted the subdivision of specialties, which, admittedly, is conducive to the deepening and deepening of the knowledge system. The development of science and technology will also cause multi-professional barriers and disconnect between them. Old architects, structures.

The building method of masters, sculptors, and craftsmen as "builders" has long been unsuitable for modern society. In the past hundred years, architectural engineering has become the cohesion and synthesis of multidisciplinary majors, and the relationship between architecture and structure [7]. The most close, it requires both division of labor, more detailed research, and coordination and cooperation between them. Structure is the skeleton that supports the building and the material basis for architectural artistic expression, although the structure belongs to science and technology, But there are often artistic considerations involved. Sexual factors. There are many architects, such as Calatrava, who are willing and good at using structural technical means to express architectural art, and have always maintained an emphasis on structural technology in their architectural creation.

5 Conclusion

The overall tensile structure is a stable self-balancing structure composed of compression members and tension members, the compression members are in a discrete state, and the tension members are in a continuous state. The tensile monolithic structure has no stiffness on its own, but is provided by self-stress. Its geometric composition and mechanical properties have not been studied systematically, and by studying the regeneration behavior of spongees, its monomer composition, path derivation, epidermal tissue and tension structure have a high degree of similarity, which provides more biomorphic reference and guiding significance for the development of reticular tension structure. On the one hand, from the built-in perspective, the "cable-membrane" structure in the tension structure is discussed, the influence of the forward and reverse structure of the rod cable on the mechanical properties of the tension membrane is discussed, and then a variety of bone needle evolution structures are obtained by discrete polymerization algorithm, and a variety of tension membrane structures are constructed. On the other hand, the "rod-cable" structure in the tensile structure is disassembled from the perspective of externalization, and the morphological evolution of the overall tensile structure under different compression modes and path conditions is discussed. The combination of the two provides an innovative idea for finding the shape of the tensile structure.

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