Study on Parametric Design of Building Special-shaped Curved Surface-External Surface

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Abstract. This paper takes the special-shaped curved building surface of Hangzhou East Railway Station as the research object, draws lessons from the theories and examples of nonlinear building surfaces and its parametric technology at home and abroad, summarizes the technical characteristics and design methods of nonlinear complex building surface, and combines the parametric design objectives, algorithms and expressions of special-shaped hyperboloid building surface, summarizes the design strategies for a technology implementation of Hangzhou East Railway Station, such as, modeling parametric design, material comparison, structural optimization and construction technology.

Keywords: Architectural special-shaped curved surface-external surface, parametric design, building surface material comparison, construction technology

1 Introduction

Parametric design is a design method that adopts a size-driven mode. By changing the size of a certain part or some parts of the graphic, the relevant parts of the graphic can be automatically changed, so as to realize the driving of the graphic by size. The geometric information and topological information required for driving are automatically extracted by the computer. We apply this design method to architectural design to simulate complex systems, taking the external surface of the special-shaped hyperboloid building of Hangzhou East Railway Station as the research object. Hangzhou East Railway Station is a super-large transportation hub station that integrates railway, subway, bus, taxi and other transportation modes, as well as supporting service facilities (see Figure 1). The station has a novel and atmospheric building shape, a tense steel structure and a smooth indoor space, which cleverly presents the image of Hangzhou's "Qiantang Tide". The complex hyperboloid external surface of Hangzhou East Railway Station is mainly applied to 26 hyperboloid special-shaped columns in the station building (4 on the east and west facades and 9 on the north and south facades). There are three types of hyperboloid special-shaped columns: one is the large special-shaped column on the east and west facades (see Figure 2), the other is the large special-shaped column on the north and south facades, and the last is the surrounding corner columns.

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Fig. 1. Panoramic view of the main station building of Hangzhou East Railway Station

Fig. 2. Hyperboloid special-shaped columns and corner columns at the west entrance of Hangzhou East Railway Station Building

The complex hyperboloid surface of Hangzhou East Railway Station is large in volume and requires continuous and smooth visual characteristics, which puts forward comprehensive high requirements for surface design optimization, structural rationality, processing, installation accuracy, cost control, etc. Therefore, in the design stage of this project, we have improved the previous modeling method in which we are modeling first and then fitting. Consequently, we can't avoid the unreasonable overall structure, and we can only adopt the modeling method of structural compensation in the later stage. And the multi-objective automatic form-finding method was adopted for the first time. While maintaining the morphological characteristics of the surface, the rationality of the structure was optimized at the same time, which laid a preliminary foundation for the later construction, installation and deformation resistance. In terms

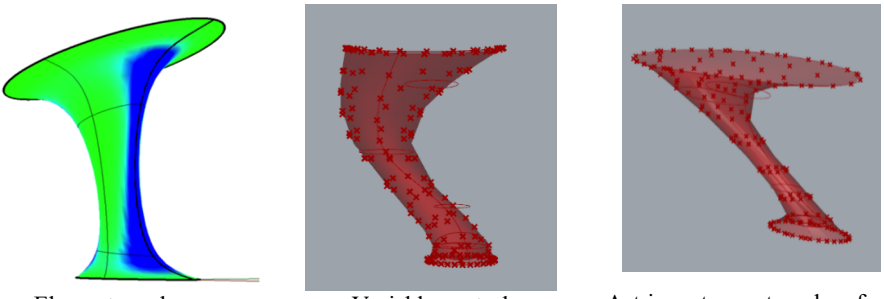
of construction technology, a variety of materials and processing methods suitable for complex hyperboloid building surfaces were studied and compared, and 1: 1 equal ratio construction samples of different materials were built on site. The surface effect, structural nodes and forming effects of different curtain wall keel forms were comprehensively compared, and a process method was designed to forge large-area surface modules in the factory, cooperate with adjustable installation nodes to eliminate errors, and finally grind and form the whole. Finally, satisfactory construction results are achieved[1].

2 Parametric Design of Special-Shaped Hyperboloid External Surface

2.1 Overall Optimization of the External Surface

By adopting the genetic algorithm, taking the nurbs control point as the displacement weighting variable, the gradient descent model is established, and the multi-objective weighting solution is adopted to achieve fast convergence and the control range of the shape deformation range can be set according to the appearance requirements, thus breaking through the weakness as follows: the slow convergence of the midpoint evolution in the traditional rectangular coordinate system, and low morphological control (see Figure 3).

Using the principle of minimal surface, the complex hyperboloid is rationalized, so that the Gaussian curvature is 0, and the strain energy is reduced, thus decreasing the occurrence of torsion in the structure and avoiding boundary deformation.



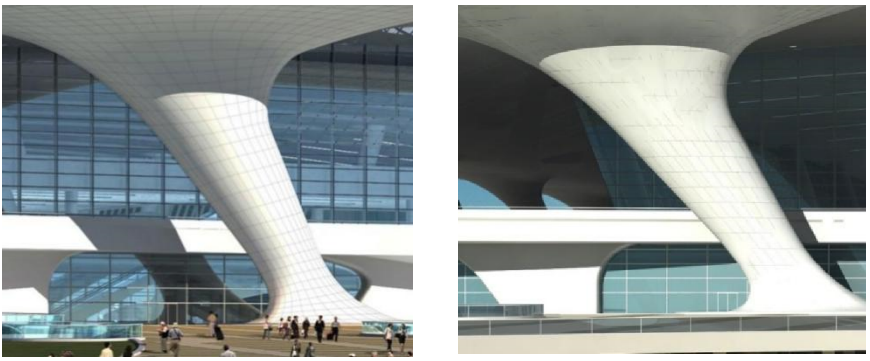
Elementary shape Variable control Astringent on external surface

Fig. 3. Gradient descent model of hyperboloid surface of large special-shaped column in Hangzhou East Railway Station

2.2 Optimization of Surface Plating

At the initial stage of scheme selection, the considered splitting scheme has different arrangement forms of staggered joints, butt joints and seamless joints (see Figure 4). Among them, the arrangement of staggered joints and buckling joints can use panel modules with smaller scales, and the gaps can be used to realize a certain surface

mechanism. At the same time, the smaller module size is relatively convenient for transportation and installation, so it is also a common practice to build a large number of free-form buildings.



Butt joint/curved plate Staggered joint/curved plate

Fig. 4. Plate optimization of hyperboloid surface of large special-shaped column in Hangzhou East Railway Station

However, although we generated a surface with a Gaussian curvature of 0 in the first step of overall optimization, this surface is not necessarily a deployable surface through the aforementioned geometric analysis, and the original panels of these two slit scheme types have a large number and different shapes, so further automatic optimization is needed on the basis of overall optimization[2].

2.3 Surface Plate Fitting

According to the maximum curvature value of the panel, a genetic algorithm is used to try to fit the single curved-surface closest to its shape, and then classified by the error values of corner points and midpoints. If the error is less than 3mm, it is allowed to be fitted as a single curved-surface, and a simple processing technology is adopted. If > 3mm, the complex machining process of hyperboloid is adopted. Note that there is basically no error in the flattening of the deployable panel, while if the hyperboloid plate is stamped from the plate, it must include some deformation[3]. Here, you should use professional software modules, such as Rhino's squish or Proe's sheet metal module, for flattening, try to fit high-precision lofting and unfolding, and then press at more points to form, or use multi-point drawing to form the sheet before carrying out panel cutting and final forming to ensure higher forming accuracy.

The split surface treatment method provides a lot of optimization space for digitally improving the manufacturing performance of the initial design. From module production to installation, it can realize complete automated design control and reasonable cost reduction and is suitable for use in a large number of complex hyperboloid or free-form surface projects. In order to achieve overall visual fluency, the Hangzhou East Railway Station project finally decided to choose a seamless design direction.

3 Comparative Study on Special-Shaped Hyperboloid External Surface Materials and Their Processes Technology

3.1 Comparison of Surface Materials and Their Processes Technology

In order to achieve the expected goal of architectural design, we selected a variety of materials suitable for special-shaped hyperboloid external surfaces in the current domestic market on the premise of meeting the effect of smooth and continuous building surfaces and as few joints as possible. We conducted a comparative study on various materials, including surface materials, structural systems, and construction technology. (See Table 1 for details).

At the same time, it is required that the selected materials should also meet the design requirements in the following aspects:

1) Material design requirements: surface strength, stiffness, durability, fire resistance and environmental protection performance all meet the specification requirements.

2) Structural system requirements: the surface can adapt to the changes of the main steel structure and can bear various load combinations.

3) Construction technology requirements: The construction technology requirements can achieve large-scale production, be simple and practical, and meet the needs of rapid construction.

Table 1. Comparison and selection of materials and processes for the exterior surface of complex hyperboloid buildings in Hangzhou East Railway Station

	Material	Processing method	Material performance	Installation process	surface treatment
Stainless steel plate	SS316	Multi-point moldless digital molding. Hand hammer art	Good processing performance, high weather resistance, more than 40 years of service life	Plate mounting	Stainless steel plate is natural color or fluorocarbon baking paint, which can be seamlessly treated
Porcelain aluminum plate	Aluminum veneer + porcelain coating	Multi-point moldless digital molding	Good processing performance, high weather resistance, 50 ~ 80 years service life	Plate mounting	The surface of aluminum plate is baking enamel paint, which cannot be treated seamlessly

artificial stone	Polyester resin composite	Die-less press forming and die-forming	High processing accuracy, average weather resistance, 10 ~ 15 years service life	Plate mounting	Artificial stone natural color, can be seamlessly processed
Fiberglass reinforced plastic (FPR)	Glass fiber reinforced plastic	Die-less press forming and die forming	High machining accuracy, poor weather resistance, 10 years service life	Plate mounting	Natural color of fiberglass, can be seamlessly processed
GRC	Fiberglass Reinforced cement	Premixed casting process and premixed spraying process	High machining accuracy, high weather resistance, more than 50 years of service life	Can be divided into large pieces of production, factory prefabrication, and various installation methods	The surface can be made into different texture effects
GRG	Fiberglass Reinforced plaster	By laminating or spraying process and moulding	Short processing cycle, high weather resistance, good flame retardant and acoustic performance, 50 years service life	Can be divided into large pieces of production, factory prefabrication, and various installation methods	The surface is smooth and fine, the whiteness reaches more than 90%, and can be made into different texture effects

3.2 Comparison of Surface Material Construction Method

Through the theoretical research on the materials and technology of hyperboloid building external surface, we selected four materials: stainless steel plate, aluminum plate, fiberglass reinforced plastic and artificial stone to build the construction sample in the same proportion of 1: 1 at the construction site, and observed and compared the construction sample for their on-site impression, simulation construction and weather resistance of materials etc.

Stainless Steel Plate.

Stainless steel plate is a material with high strength, high toughness and low maintenance. Its toughness is high and it is suitable for arc bending with large curvature. However, on the other hand, the problem of residual stress needs to be considered during the processing of stainless steel plates to prevent warpage and deformation from affecting flatness. There are two main existing processing methods: one is dieless digital forming based on cad/cam industry chain, and the other is hammer forging represented by traditional handicrafts. The former has been verified in many successful projects. However, in order to achieve the optimization of local fitting, this surface system also has the discrete characteristics of computer molding technology. Its external characteristics are that the panel blocks are relatively small, and there are many connection nodes with the keel. The complexity of on-site installation is often reduced by leaving joints between plates (see Figure 5). In this project, the plates are welded according to the modeling needs to become a seamless whole. As the highlight of Hangzhou East Railway Station, it is not very suitable for digital fitting and forming of large quantities and small blocks.

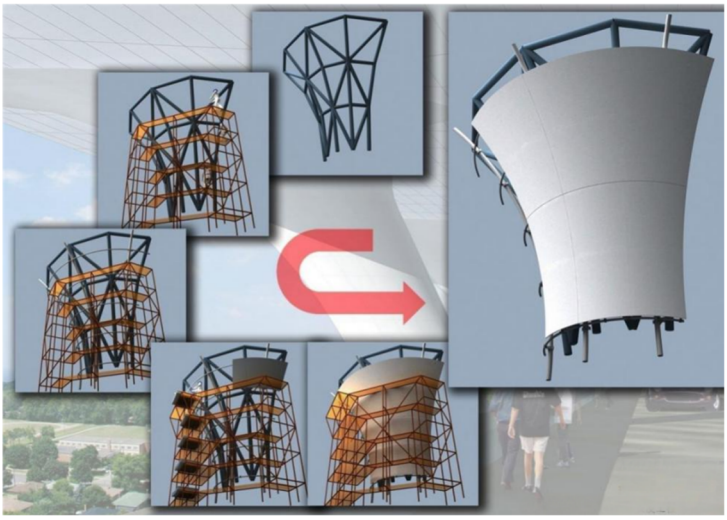


Fig. 5. Stainless steel material scheme and technical implementation of hyperboloid surface of large special-shaped column in Hangzhou East Railway Station

Porcelain Aluminum Plate.

Aluminum plate is a widely used material in curtain wall systems of large public buildings at home and abroad, and porcelain aluminum plate is a composite decorative material formed by coating water-based ceramic coating on aluminum alloy plate and drying and hardening. From the processing point of view, porcelain aluminum plates and stainless steel are both metal plates, which are suitable for similar sheet metal processing technology. They can be bent and folded. Similarly, flat porcelain is easy, but hyperboloid porcelain is very difficult. From the construction point of view, it is light in weight and does not require further surface treatment after installation. In

addition, its surface finish is high, and it has the characteristics of self-cleaning and good durability, so it is a surface material with excellent characteristics from installation to use.

However, the method of forming aluminum plates in the factory, completing surface treatment, and then transporting and installing the prefabricated modules determines that the secondary surface treatment, such as welding, painting, and polishing, cannot be carried out between the plates, and only the excess between the plates can be treated by splitting seams (see Figure 6). Therefore, it can't meet the visual requirements of smooth and seamless special-shaped columns in Hangzhou East Railway Station.

Fig. 6. Hangzhou East Railway Station Large Special-shaped Column Hyperboloid Surface Ceramic Aluminum Plate Material Scheme and Technical Implementation

Fiberglass Reinforced Plastic (FRP/GFRP + CFRP).

The scientific name of fiber-reinforced plastic is fiber-reinforced plastic, commonly known as FRP (Fiber Reinforced Plastics), that is, fiber-reinforced composite plastic. FRP demonstrates the following characteristics: lightweight, high strength, and good resistance to atmosphere, water and general chemical solvents. Reinforced fiber plastics can be designed into products of various shapes according to needs. They have good plasticity and are easy to process. However, like all plastic products, they have the common defect of aging, and their performance decreases over time under the action of ultraviolet rays and stress. It has poor weather resistance and durability, and only has a service life of about ten years. Therefore, considering the cost of the whole life cycle, although the cost of fiberglass is low in the short term, the cost of use is higher than that of steel. Because FRP is thermoplastic, its processing technology generally uses frame mold and multi-jog mold hot forming (see Figure 7).

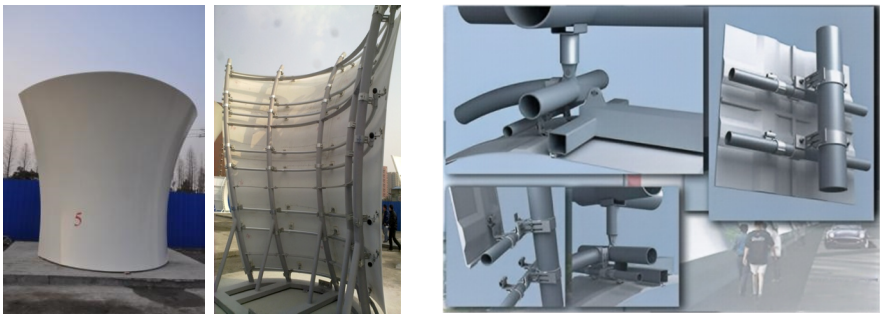


Fig. 7. FRP material scheme and technical implementation of hyperboloid surface of large special-shaped columns in Hangzhou East Railway Station

Artificial Stone.

Since the successful research and development of artificial marble (referred to as artificial stone for short) in the 1960s, it has been divided into artificial stone with unsaturated resin as the bonding material and artificial stone with Acrylic modified resin (Acrylic) as the bonding material according to the raw material resin used. Artificial stone has excellent processing performance and is thermoplastic without residual stress, with high surface accuracy, can be seamlessly spliced by chemical welding, and its shape is ever-changing (see Figure 8). The Babbitt hardness of ordinary artificial stone is between 58-62, which makes it easy to scratch compared with metal. Moreover, the stone in its composition is a porous material, which will absorb water, so the surface will become damp and yellow over time, so it needs regular maintenance and cleaning. At the same time, if the local stress in the keel system is uneven, it may cause the artificial stone of the surface material to be deformed, curved and cracked, and if it falls off, it will cause potential safety hazards to pedestrians[4].

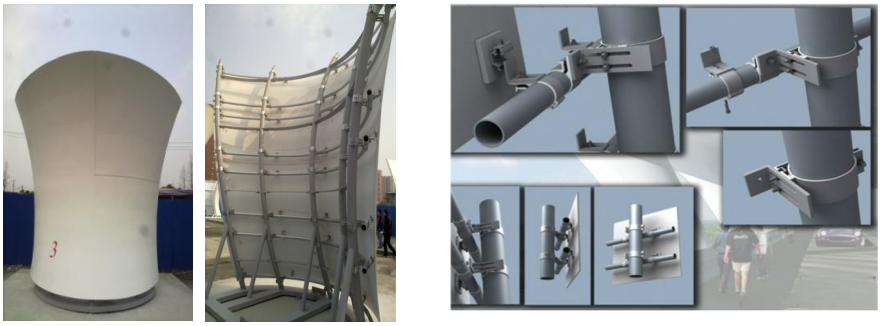


Fig. 8. Hangzhou East Railway Station Large Special-shaped Column Hyperboloid Surface Artificial Stone Material Scheme and Technical Implementation

3.3 Comprehensive Analysis of Materials

As shown in Table 2, through the comparison and selection of various material schemes and technologies implementation, it can be found that:

1) From the comparison of material properties, durability and construction technology, three materials: aluminum plate, stainless steel and artificial stone can meet the requirements. The durability of fiberglass can't meet the requirements.

2) The seamless hyperboloid external surface can be made of stainless steel or artificial stone.

3) The seamed hyperboloid external surface can be made of stainless steel, aluminum plate or artificial stone.

4) Economic comparison: aluminum plate is the best, stainless steel is the most expensive, and artificial stone and fiberglass are in the middle.

5) Aluminum plate (porcelain) is recommended for the seamless surface solution, and stainless steel plate is recommended for the seamless surface solution.

Combined with the comparative analysis of materials, the ideal materials with high alignment with the hyperboloid special-shaped building surface of Hangzhou East Railway Station (material thickness, average cost, combustion grade, service life) model include porcelain aluminum plate and stainless steel plate, and because the modeling needs to realize seamless surface, porcelain aluminum plate can't meet the requirements, so stainless steel plate is the only selected material.

Table 2. Comparison and selection of surface materials for hyperboloid special-shaped buildings in Hangzhou East Railway Station

	Specifications	material	performance	Service life	Comprehensive unit price (yuan/㎡)	Effects
Porcelain aluminum plate	3mm thick aluminum veneer	Aluminum veneer + porcelain coating	Fire Rating: Class A; Hardness ≥ 5 H; Fire resistance: > 600 ℃, non-combustible; It is easy to clean.	50-80 years	1600	The transition of hyperboloid is natural, and the split seam can be made into butt seam or wrong seam, but it cannot be seamless.
artificial stone	12mm thick im-	Composite material prepared by	Density: 1.693 g/cm ³; Specific gravity 1.697; Fire resistance: B1;	10-15 years (free	3000	The hyperboloid transition

	ported artificial stone	mixing unsaturated polyester resin with filler, pigment and initiator	Flexural strength: 67.4 Mpa; Impact strength: 5.7 kj/m ³.	replacement within 5 years)		is natural and can be done seamlessly.
Stainless steel plate	2mm thick stainless steel plate	SS316	Tensile strength: 520 Mpa; Drop intensity: 205 Mpa; Elongation: 40% MIN; Hardness: 90HRB MAX.	40 years or more	3500	Split sewing can be done butt sewing, staggered sewing and seamless treatment.
FRP	8mm thick fiberglass	Glass fiber reinforced plastic	Tensile strength: 159 Mpa; Flexural strength: 178 Mpa; Bending modulus of elasticity: 3000 Mpa; Impact strength: 15.4 J/cm ²	10 years (slightly poor surface treatment adhesion, poor weather resistance, shorter warranty period)	2600	The hyperboloid transition is natural and can be seamless, but the rebound deformation is serious.

4 Construction Technology of Complex Hyperboloid External Surface

4.1 Surface Structure and Installation

The complex hyperboloid external surface of Hangzhou East Railway Station is mainly applied to 26 hyperboloid special-shaped columns of the station building (4 on the east and west facades and 9 on the north and south facades). Among them, the large special-shaped columns, the top of the inter-rail columns and the inner side of the four-corner columns are seamless stainless steel plates, the large special-shaped columns and the inter-rail columns are hyperboloid stainless steel plates, and the four-corner columns are flat plates and single plates. The total area of stainless steel plate is about 15500m2.

The hyperboloid curtain wall structural support system of Hangzhou East Railway Station is composed of curtain wall beams and columns. The curtain wall columns are connected with the main steel truss nodes through hinge supports[5]. The curtain wall beams are welded and fixed on the columns. Both the beams and columns are set with breakpoints to adapt to expansion and contraction deformation. The external surface unit plate is hung on the beam of the curtain wall and is circumferentially stressed.

The curtain wall surface of the large special-shaped column in Hangzhou East Railway Station is made of steel pipe bent and welded into a curved grid shape. The stainless steel plate is covered by a hammer forging process on the shaped steel pipe. Finally, the shaped steel pipe and the stainless steel plate are welded and fixed according to the welding machine code, and the surroundings and middle are supported by large steel pipes.

4.2 Surface Treatment of the Curtain Wall

Hammer art: Hangzhou East Railway Station's complex hyperboloid large special-shaped column adopts dieless forming forging hammer technology art for metal material forming. Hammer craft refers to a craft technique in which professional hammer artists use keys, chisels, non-standard iron pads, and commonly used gold-pulling tools to hammer metal materials hot and cold. After hundreds of years of development, hammer art has evolved into a modern craft technique that can achieve precise and complex shapes. The special-shaped columns of large special-shaped columns in Hangzhou East Railway Station are very complicated in shape and completely different in curvature. The mechanical bending method can't completely guarantee an accurate appearance, the surface interface is not smooth enough, and the curved surface effect is stiff and dull. Only by using the method of manual hammering art and combining it with the traditional hammering art tire frame to make a special-shaped curved surface unit, can the most complex, accurate and smooth curved surface effect be achieved.

Painting: In the factory, the stainless-steel external surface of the whole unit is treated with epoxy primer, and the partial uneven parts are leveled with atomic ash. After the unit plate is transported to the site, it is welded and polished, and partially leveled with atomic ash. The columns were maintained on site to form a relatively closed, clean and tide space. Finally, the columns were treated with epoxy intermediate paint and fluorocarbon topcoat.

5 Conclusion

As one of the largest hyperboloid seamless exterior surface projects in China at present, the whole process design and manufacture of complex hyperboloid building exterior surface in Hangzhou East Railway Station has accumulated valuable practical experience and first-hand information for the development of nonlinear complex building exterior surface in China, and achieved the balance of complex hyperboloid building exterior surface in architectural effect, structural safety, construction technology and

construction cost, and the project achieved good results, which provides a good reference and guiding significance for similar projects in the future.

Acknowledgments

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References

1. Li Xiaoan. Optimal Design and Construction of Irregular Curved Metal Surface--A Case Study of Dongdaemun Design Plaza [J]. Architectural Arts, 2015, (10): 94-99. [2017-10-05].
2. Zhang Jian, Liu Chang, Xu Bing. Key technologies and application examples of multi-platform fusion structure analysis and parametric design [M]. China Building Industry Press, Beijing, 2023.
3. Chang Bo, Mei Xianzhong, Wei Longrui. Construction technology of hyperboloid stainless steel curtain wall with special-shaped columns on east and west facades of Hangzhou East Railway Station Building [J]. Construction Technology, 2017, (10): 68-71.
4. Yang Xihui, Zhang Aimei. Creo Parametric surface design and parametric modeling [M], Xidian university Publishing House, Xi'an, 2024.
5. Yan Hainan, Grasshopper Parameterization Technology: From Basic Modeling to Digital Design [M], Huazhong University of Science and Technology Press, Wuhan, 2022.