Research on Eco-shaping Architectural Design

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ABSTRACT

Form, as the physical bearer of both the architectural meaning and function having being increasingly engineering focused by the designers and users in todays' context, which corresponding with the changing and developing in science, society and also aesthetic. With this trend, form generation methods have gradually become an important branch in the field of design research. Meanwhile, computer aided techniques and ecological simulation platform also progressing rapidly as a result of massive increased application requests. Theoretically, the three have great potential and significance in integrated application. The present thesis is the result of the efforts devoted to developing the issues of the integration of the three-Form Generation method, Parametric Design, and Architectural Ecological Simulation -from theory possibilities to practical application.

This paper proposes the theoretical framework of Eco-shaping Architectural Design Approach, explains its work flow and verifies the effectiveness in one architectural design practice. Based on the cross discipline filed of parametric design and architectural ecological simulation. The study start with the simulation of environmental factors affecting the architecture's ecological performance such as solar radiation and wind field. Based on the theoretical foundation of Complexity Science, Form Generation, and Performance Driven Design. Powered by Parametric Design technique and Building Performance Simulation technique as the operate platform. Using a method combined bottom-up self-organized generating and up-down performance driven optimizing.

The study reveals the application process of how the environmental factors be transformed into the driven force of form shaping and using genetic algorithms to optimize the result. Bridges the data gap between parametric design platform and building performance simulation plat form by quadratic programming under Grasshopper. And finally points out the technological superiority and limitations of the architecture form generative method and the problems requiring further studies are discussed.

Key Words: eco-shaping, parametric design, environmental simulation, genetic algorithms

Chapter 1 Introduction

1.1 Research background and significance

1.1.1 Research background

Architecture is the art to construct space, and the physical form is the first method to exert influence on its users. The architecture's space and function need to be realized by form and the architecture's sense and connotation also need to be expressed by form. As the bridge between aesthetic value and actual construction, the architectural form and evolvement are also influenced by external factors such as social concepts, science and technology and environment[1].

The architectural form styles reflect the epochal characters of the current age. In ancient Greek, the pursuit of grand beam column system was a concentrated reflection of its slave society system and philosophical thinking. Ancient Rome's obsession in centralized large space reflected its superb arch construction technology and expanding empire territory. When Gothic buildings and free city layout arose together with feudalism, the ideal self-organizing architectural style stressing accurate proportion in renaissance started to give out the illuminative brilliance of rationality in those cities in the north of Italy where the early capitalism developed rapidly. Concentrating on the modeling of spatial continuity, the rise of Baroque architecture was accompanied by the emperor's increasingly rising authority and absolute dominance of territory. Growing in the diverse social system, the middle class was represented by the simple neo-classicism. In the process of democratization after the war, under the voice of the growing working class, with the bright brand of Fordism in the age of industrial production, the radical and abstract modernism started to include worldly architecture into the concern of architecture discipline. In the ascendant of modernism architecture, postmodernism and deconstructivism are making unremitting efforts to deal with the surging communication and complexity of social life in the post-industrial age. [2]

At the present time, under the heated wind of globalization, the diverse development trend in culture has greatly promoted the wide communication,

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[1]. Zhang Xiangning. Science Agent for the Aromorphosis of Architecture. [Doctoral Dissertation. Harbin Institute of Technology. 2009.

[2]. Patrik·Schumacher. Parametricism. Time Architecture, 2012, 05: 22-37

intersection and merging among different art forms and disciplines. Under the impact and influence of the complex science represented by chaos theory and emergent theory, the philosophy of postmodernism represented by Deleuze's decentralization theory, as well as the new technology represented by digital design and digital construction, the border of disciplines have been broken down, and a revolution pursuing the "innovation" of architectural form has been initiated.

At the same time, discussion on morphogenesis has never ceased. At present, under the background of diverse disciplinary development of architecture, morphogenesis theories including Emergent, Deformation, Folding and Animation have emerged. For example, John Hollander puts forward the system, model and their rules and laws of the phenomenon "Emergent". He believes that just like the biological system in nature, architecture should have complexity limited by simple rules, and the systematic regular superposition can create seemingly infinite possibility. And he also stresses that the reason why people are more willing to focus on simplicity and mechanically restore it is that they are limited by research techniques and methods, but not to admit that simplicity is the real essence of things, which also further makes us unable to interpret and percept the complex phenomena[3]. In the theory of "Animation Form", Greg Lynn views the architectural special form as a physical state under the dynamic balance constituted by difference and force[4]. John Frazer puts forward the morphogenesis theory of "Evolution Architecture", which stresses that like the living organism, architecture should also conduct self element organization and self behavior adaptation[5]. FOA office puts forward the theory of "developmental morphology", and then constructs the generative system tree based on the seven response factors[6]. NOX office puts forward the morphogenesis theory of "Fussy Structure" and realizes the interactive dialogue between architectural form and users through interaction media[7].

Although morphogenesis theory is of multiple branches with different characteristics, in terms of its ideological core, architecture is viewed as an existence like the living organism rooted in specific field domain rather than a man-made shelter to satisfy specific usage requirements. Architectural morphogenesis is defined as a morphological self-organizing development process in response to one or several

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[3]. John Hollander, Order out of Chaos [M](Chen Yu). Shanghai: Shanghai Science and Technology Publishing Company, 2006. 25-30

[4]. Greg Lynn, Animate Form[M], New York: Princeton Architecture Press, 1988: 16

[5]. Frazer J H, An Evolutionary Architecture[M]. Architecture Association. London, 1995:65-68

[6]. Foreign O A. Poylogenesis: foa ark[M]. Barcelona: Actar, 2003: 23-24.

[7]. Las S. The Structure of Vagueness[M]. NOX: Machining Architecture. Las Spuybroek ed. London: Thames, 2009: 352-359.

external forces based on certain or several kinds of specific logic. Through this process, the final architectural design is achieved. The previous top-down model of creation is transformed into the bottom-up generating scheme.

The generation of the form needs the setting of logic and the input of parameters. “Parametric design”, a new design method arising with the rapid development of computer technology, has provided a practical and effective technical support and implementation platform for the development of morphogenesis theory as well as the practice of its design ideas. Since the birth of the first computer plotting system in America in the 1950s, due to the development of CRT and graphic input techniques like the mouse, since the early 1990s, the computer, gradually replacing the drawing board and T-square, has become the major tools for architects to deliberate and adjust their design plans, announcing that the application of computers in the design domain entered the stage of Computer Aided Drawing. Though in this period, computer aided design was mainly used for drawing and expression[8], the generalized parametric design already appeared. That is, in the process of graphic plotting and modification, the involved operations are nothing more than the operation and modification of the underlying data in the drawing program, and in response to other parts of the drawing by its relevance to the program, it is finally reflected in the user interface on the surface of the program, thus realizing the purpose of drawing, modification and adjustment. This is a single constrained parametric process, i.e. “input-feedback” model.

The development of new technology will certainly promote the emergence of new methods. At the beginning of this century, a more advanced Computer Aided Design appeared. This design method aims to define the responding logic of the final result to the input parameter and further influence the final design through users’ establishing connection between variable input and output by defining the logical relationship among objects. This method is concerned about the logical relationship among objects rather than the concrete forms, which quantifies the data and establishes mutual constraint in the design process simultaneously, so it is a multi-dimensional parametric process, which can be abstracted into “input-logical function-feedback”—“ parametric design” is usually referred to in the current context.

Architecture was once viewed as the materialized draft, but today, this viewpoint is gradually replaced by the materialized information. Since the new century, parametric

[8]. Boddy R C,Wetherill M. Computer integrated construction: A review and proposals for future direction[J]. Advances in Engineering Software, 2007, 38(10): 677-687.

design has increasingly referred to the research achievements in other disciplines such as “genetic algorithm”, “swarm intelligence” and “machine intelligence” to generate and optimize the designing schemes. Parametric design has truly become a fashion and been studied, popularized and applied by a batch of pioneering architects and theorists. For example, Kostas from Harvard University made used of “formal grammar” to construct an architectural self-generating system based on logical construction of language[9], Schoch Odio and Paul Coates made use of the cellular automaton and genetic algorithm to construct the generative system, and offices like UN Studio, B.I.G and Zaha Hadid also developed relevant practical activities and constructed some complete works. In the new address design of CCTV, OMA office and ARUP engineering consulting company made use of mechanical analysis results to construct its surface. In the design of London City Hall, Norman Forster confirmed the form of the building according to the sunlight. Thus we can see that parametric design provides a new concept and method for the creation of the architectural form.

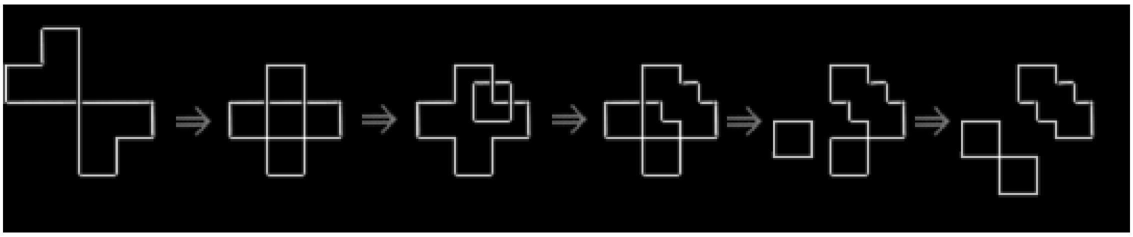

Chart 1-1 Generation Schema of Formal Grammar[10]

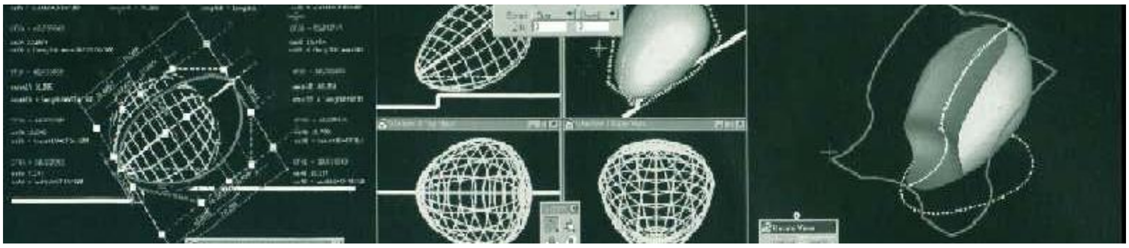

Chart 1-2 Form Design of London City Hall[11]

Since architecture generates from its environment, it is not likely to be an isolated space limit behavior, instead, it is a part closely connected with the natural system. Following its history, in the early stage, masters of modernism put forward different thoughts on simple ecological sustainable development, for example, Le Corbusier put forward the stilt building and roof garden in his “5 points of new architecture” in 1925,

[9]. Kostas Terzidis. Algorithmic Architectur[M]e. Architectural Press, 2006: 73
[10]. Kostas Terzidis. Algorithmic Architecture[M]. Architectural Press, 2006: 26
[11]. Branko Kolarevic. Architecture in the Digital Age: Design and Manufacturing[M]. New York & London: Spon Press, 2003: 85.

and Fuller was devoted to the practice of obtaining the maximum space structure system with the minimum consumption; in the 1960s, in *Design with Climate: Bioclimatic Approach to Architectural Regionalism*, Victor Olgyay put forward bioclimatic localism, which took the satisfaction of human bodies' comfortable sensation as the starting point of the design; till the 1980s, in James Lovelock's work *Gaia: A New Look Life on Earth* and the Gaia Movement driven by him, he viewed the earth and various living systems on the earth as entities with vital signs and human beings only as a part of it. Arcology gradually feeds into the ideology of the architectural design. Under the current background of environment degradation and resource starvation, ecological sustainability is increasingly becoming the theme of architectural design.[12]

[12]. Song Yehao. Overview on the Development of Ecology Theories in Europe and America. Time Architecture, 1998, 01: 67-71

As one of the accomplishing means of arcology, since the 1990s, arcology evaluation system has been established one after another around the world, such as the British BREEM, American LEED, Canadian GBC and Japanese CASBEE. The evaluation respects differ from each other in building energy efficiency, users' feelings and impact degree on environment. But their action mode is universally to have a directional guidance on the design process through conclusive evaluation as well as the derived sub-item guidelines. Meanwhile, with the development of computer technology, computer model analysis software of architecture's ecological performance paying more attention to the direct application in the conceptual level emerges and is used, such a series of performance model analysis platforms like Ecotect Analysis, Phoneics, Radiance, Energy Plus, Vasari and Doe-2. The analysis results are shown in the form of data, and compared with evaluation guidelines, it is much easier to provide basis and support for the design process and offer ecological basis to the generation of architectural form.

1.1.2 Research Purpose and significance

With the development of science, society and the change of aesthetical standards, as the substantial carrier of building function and significance, architectural form is receiving more and more attention from the architectural design and appreciation subjects under the current context, and thus, the corresponding architectural morphogenesis method is gradually becoming an important branch of the design

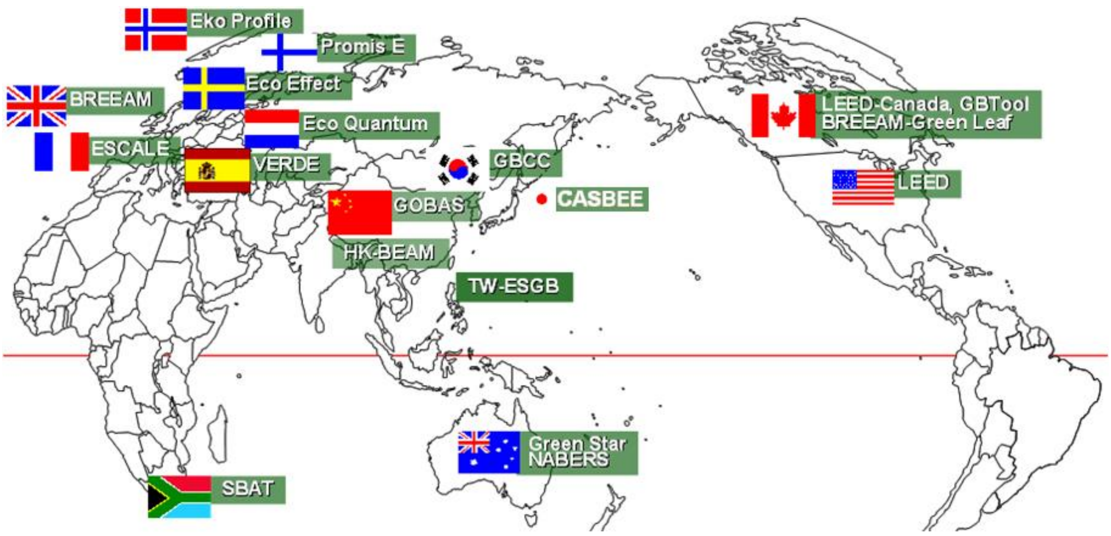

Chart 1-3 Evaluation System of Green Architect

research field. At the same time, computerized design technique and architectural ecological simulation platform represented by parametric design also develops rapidly with the increasing demands of application. Theoretically speaking, these three are of huge potential and significance in integrated application, but as there hasn't been much research on this field for long, this thesis is a whole set of research focusing on the integrated application from theory to operation of the three——architectural morphogenesis, parametric design and architectural environmental performance simulation.

Architectural form is the major transmitter of the its significance and the accomplishing means of its function, and under the current context, its generation type is no longer restricted to the internal category of architectural disciplines, but instead, it is mixed with the knowledge and outcome of multiple disciplines, intersected with environmental sciences, social sciences and materials engineering. In virtue of the development of parametric design technology, its process can transform the generating logic to self-organization rules, parameterize the generative process into smaller program components and transfer the difficult creation black-box into clear and specific programming behaviors.

However, throughout the current study and practice, the architectural morphogenesis methods also have problems in three aspects.

Firstly, when the generative process is divorced from designers' subjective control and is fully taken over by establish procedures, the final result derived from the "absolutely objective" generating logic sometimes can't accord with the accustomed aesthetic logic and design requirements. This wild result may stem from the inaccurate or incomplete definition of the generating logic, and it is also probably because the geometric model of the generating logic subjects to the current computer arithmetic efficiency, and in usage, the information is lost in the operation of model simplification.

Secondly, when the design process is divorced from the generating program derived from the objective conditions and it is handed over to designers to complete the translation of generating conditions and mechanism so as to further complete the design, usually circumstances will occur when generating conditions are overly abstracted or conceptualized, so that the final result has a great displacement with the initially generated dimension and the generating logic lacks rationality, which can't reflect the scientificity of morphogenesis and provide rich and efficient logic for morphogenesis.

Thirdly, though the design concept of "ecological shaping" runs through it, in practical operation, subjective and objective analysis of the design is different in different stages, the design methods are distributed in different platforms by different ways, and the data flow among different platforms is unsmooth, which may lead to various data breakage and loss in the conductive process. As a result, the complicated information is often overly simplified and restored, which hasn't played a due role in the ecological shaping process.

Thus it can be seen that it is the backward design method that restricts the development and application of ecological architectural morphogenesis.

Aiming at the issues above, the thesis introduces ecological performance simulation technique and parametric design technique to architectural morphogenesis method to form a closed "concept-optimization-design" procedure and establish an architectural morphogenesis method based on environmental and ecological factors. Meanwhile, it combines the bottom-up computer program generation with the top-down designer subjective control to optimize this design method so as to make it better applied to the practical design projects.

To be more specific, it focuses on realizing the research purpose of four aspects.

Firstly, mathematical logic conversion is conducted on the architect's subjective design concept, which makes it applied in digital design platform.

Secondly, ecological performance simulation procedure is closely connected with architectural morphogenesis process to construct the architectural morphogenesis logical frame based on the influence of sunlight, wind and other environmental factors.

Thirdly, by making use of the existing quadratic programming technique of the parametric platform, the thesis establishes the data transmission route and simulation evaluation platform throughout the whole design process and compiles relevant generation control program to realize the architectural morphogenesis design method based on ecological factors.

Lastly, combined with specific design, the thesis demonstrates the architectural morphogenesis design method based on ecological factors, and expounds its technical features and limitations so as to offer reference to its application.

The research significance is as follows:

Firstly, by endowing the architectural morphogenesis with currently significant parametric design technique and the currently popular ecological design strategy in architectural design, it provides a new application space for the design method of architectural morphogenesis, and through the intercrossed application of different disciplinary knowledge, it optimizes the rationality of morphogenesis theory.

Secondly, the multisystem integrated design flow, method and frame established in this research can avoid the defects in single application of different parts of the system, explore and enlarge its integrated advantage, making it better used by the design.

Lastly, the research provides a new technical platform and application mode for the ecological sustainable building design, deepens the application of quantitative analysis in sustainable design, promotes the responsiveness to sunlight and wind environment in the architectural morphogenesis process, and improves this design method's availability in the protocol stage.

1.2 Research overview at home and abroad

1.2.1 Theoretical research at home and abroad

Whether from the perspective of the importance of thoughts and theories or the operability of architectural practice, Greg Lynn's architectural theory and practice have a profound guiding significance on the development of parametric architectural design. In his practice, he expresses the mobility, flexibility and complexity of the modern technology with the help of architectural words. Usually, this kind of design attempt with certain flexibility will proceed according to the flowing space formed by the surface with precise changes. This coherent form language with certain integrality has been developed in the practice of many fields in recent years. In the book *Form*, his theory and practice are explained comprehensively.

In the aspect of structure, parametric design is also well applied. The book *Informal* introduces the architectural practice[13] of a structural engineer Cecil Balmond. In this book, from the perspective of a structural engineer, the "heteronomy" of structural element and system is taken as the starting point of the design method to analyze the architecture's formation method. The author lists a series of physical and mathematical definitions related to structure as well as a series of architectural forms and spatial combination ways which are seemingly random but have deep inner orders and connections. At the same time, the author demonstrates the practical application of these abstract concepts in virtue of some design projects and constructions, which overturns the traditional thinking habit and operation order of "architecture comes first, while construction comes second".

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[13]. Cecil Balmond. Informal[M]. Prestel USA. 2007: 12,3, 56, 67

In the book *Algorithmic Architecture* written by Kostas from Harvard University, the author puts forward the generative “grammar” of architecture[14]. He believes that in a way, “arithmetic” is a kind of language structure. A generative grammar is like a language, which has its unique framework, extensibility, autogeny and flexibility. As the subject of the generating activity, architecture is naturally endowed with this feature. By subdividing the problems in the design, recombining them in a certain structure and finally making multiple deductions on different possibilities of architectural generation, it can make up for human brain’s defect in this aspect, thus helping to select a solution according to subjective expectations or objective requirements among various deduced results. Kostas believes that this brand new design system can permanently solve the contradiction between “form” and “logic” in architectural design.

Kera Lagios from Harvard University connected Grasshopper visual programming platform with luminous environment analysis platform Radiance through a interface program so as to realize the connection between luminous environmental data and architecture’s window size and establish the parametric design system based on

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[14]. Kostas Terzidis. Algorithmic Architecture[M]. Architectural Press 2006: 73

Radiance platform lighting simulation technique[15].

In *Parametricism – The Parametric Paradigm and the Formation of a New Style*, Patrik Schumacher (partner of Zaha Hadid office), based on Niklas Luhmann’s sociological theory, analyzed the epochal character of architecture and its corresponding relation with its social and economical background, and raised that parametricism would become the fifth epochal character belonging to the 21^{st} century following renaissance, baroque, neo-classicism and modernism. [16]

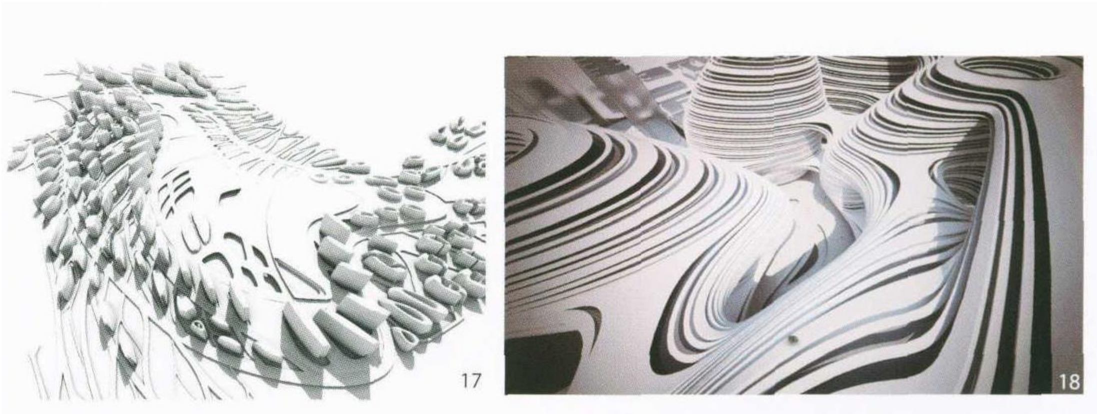

Chart 1-4 Parametric Reality (Left), Beijing Milky Way Soho (Right), Zaha Hadid[17].

Go Kawakita from Oxford Brookes University put forward the Responsive Fa çade Design System based on Ecotect. This system takes genetic algorithm as the optimization selection method, and by using Lua language programming, it selects suitable fa çade window type according to the illumination of the preset indoor sampling location, and through the weight value setting in different sampling locations, completes the reaction of usage demands to program selection and realizes the control of the light environment data over architecture’s window position and quantity[18].

In his master’s thesis, Michael van Telgen from Eindhoven University of Technology in Netherlands connected BIM structural simulation platform Oasys GSA with the visual programming platform Grasshopper through the plug-in, and made use of genetic optimization algorithm to realize the stretch-draw arch structure optimization based on structure parameters.

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[15]. Fakhri B, John F, Robin D. Evolutionary Algorithms for Sustainable Building Design[C]. The 2nd International Conference on Sustainable Architecture and Urban Development, Jordan[J], 2010: 1-15.

[16]. Patrik·Schumacher. Parametricism. Time Architecture [M], 2012: 22-37

[17]. Zaha Hadid Architects.

[18]. Han Yunsong. A Study on Architectural Morphogenesis Methods based on the Influence of Sunlight and Wind Environment [D]. Harbin: Harbin Institute of Technology, Master’s thesis, 2012:4-5

Aste Ploug Henriksen from Humboldt University of Germany applied performance optimization platform Ecotect to connect with visual programming platform Grasshopper so as to optimize the architecture's form and room layout based on the room's luminance and thermal losses caused by window-wall ratio.

Mostapha Sadeghipour Roudsari from the School of Design in University of Pennsylvania, introduced an effective visual immediate feedback architectural design-evaluation dynamic loop system in his thesis. Through a form capture device, the system could catch and dispose relevant parametric digital model in time while allowing designers to operate the solid model. In virtue of Ladybug, a plug-in based on Grasshopper parametric design platform, the data linkage between digital modeling and performance analysis was carried out, which achieved a terrific result[19].

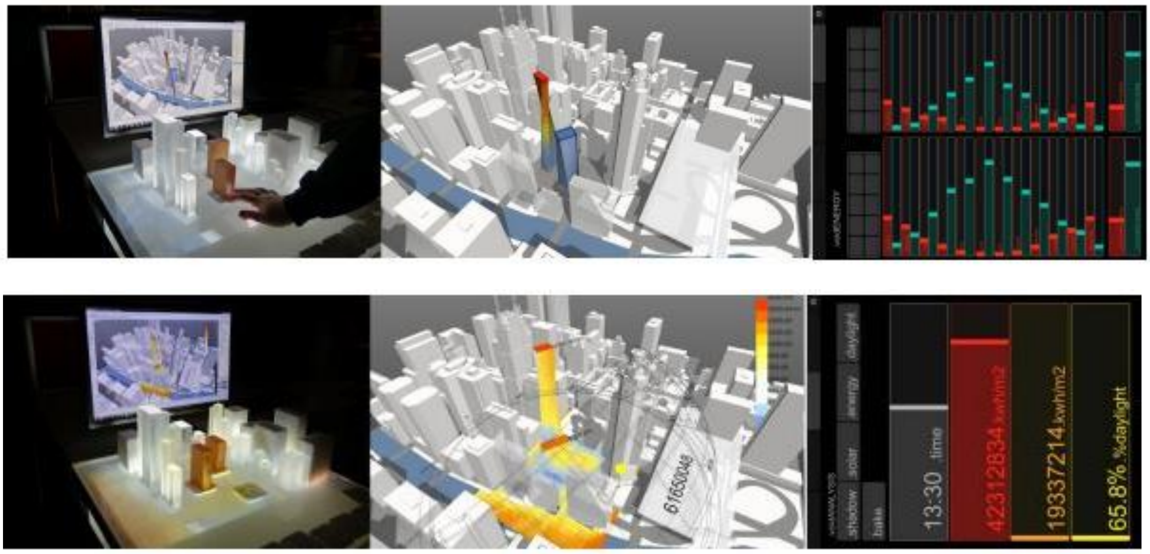

Chart 1-5 Visual Immediate Feedback Evaluation System[20]

Thomas Grabner from Innsbruck Technical University in Austria developed the Geco plug-in based on Grasshopper parametric platform. This plug-in can realize the seamless connection between performance simulation analysis software Ecotect and parametric design platform Grasshopper, achieve the function of sunlight calculation and luminous environment, and allow users to individually invoke Ecotect program function through user-defined Lua order so as to realize more user-defined data calculation and analysis.

Professor Sun Chengyu from Tongji University had a discussion about the

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19. Anthony V, Mostapha S R, Adrian S etc. An Innovative Workflow for Bridging the Gap Between Design and Environmental Analysis[J]. 13th Conference of International Building Performance Simulation Association. France. 2013:26-28

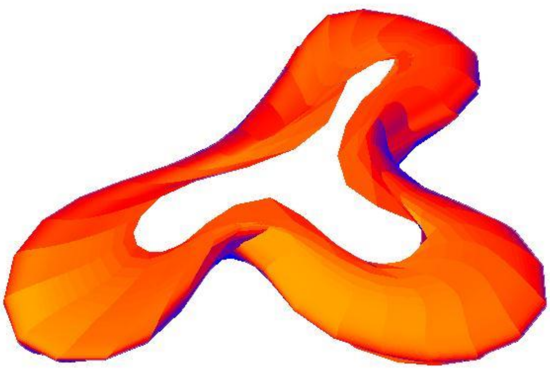
20. http://www.ibpsa.org/proceedings/BS2013/p_2124.pdf.

definition of parametric design from its broad sense and narrow sense, and summarized its corresponding design philosophy and design method in his work[21]. At the same time, taking the design of the space corridor between the two buildings of Sino-French Center in Tongji University as an example, with sunlight factor as the optimized parameter, he introduced a parametric ecological design and optimization method aiming at variable unit structure system based on Ecotect and Grasshopper.

Professor Xu Weiguo from Tsinghua University analyzed the rationality of architectural generation and creation under the complex background of science. Meanwhile, he also explained the thinking characteristics and operation methods of generation thinking in the conversion process, and explored the basic principles and practice of cellular automation system, complex multi-body intelligent model system as well as genetic evolutionary algorithms.[22]

By relying on course design, Professor Ni Xiangyu from Southeast University elaborated the design generation strategy of interaction, self-organization and survival of the fittest, explored and studied relevant data structure and arithmetic of morphogenesis[23].

In his master’s thesis, Han Yunsong discussed the architectural morphogenesis design method based on natural factors including sunlight and wind environment, and verified this method by using specific examples[24].



	日照辐射强度数据Wh/m2		日照辐射强度数据Wh/m2
0	3238.529541	4987	218.816116
1	3234.317383	4988	205.414215
2	3241.859863	4989	207.754608
3	3259.05957	4990	222.003021
4	3281.83252	4991	244.485397
5	3305.084473	4992	272.003754
6	3323.579102	4993	318.41925
7	3332.571533	4994	485.235443
8	3328.36377	4995	653.022278
9	3311.509521	4996	816.142883
10	3285.383789	4997	967.325012
11	3253.013672	4998	1100.479858
12	3217.181885	4999	1214.451416
13	3180.692383	5000	590.44574
14	3147.376709	5001	657.892822
15	3121.952637	5002	701.620911
16	3109.515137	5003	713.799072
17	3112.040527	5004	697.571655
18	3125.916748	5005	682.674438
19	3145.394531	5006	618.733582

Chart 1-6 Form Optimization based on Solar Radiation Value[25].

[21]. Sun Chengyu. Introduction to Digitalized Architectural Design Method [M]. Shanghai: Tongji University Press, 2012.
[22]. Xu Weiguo. Parametric Design Arithmetic Generation [J].World Architecture, 2011(6):110-111.
[23]. Ni Xiangyu. A Primary Exploration of Architectural Design—Taking “Happy+Lattices” Course Design as An example [D]. Nanjing: Master's Thesis of Southeast University, 2007: 41-44.
[24]. Han Yunsong. A Study on Architectural Morphogenesis Method Based on Sunlight and Wind Environment [D]. Harbin: Master’s Thesis of Harbin Institute of Technology, 2012:1-3.
[25]. Han Yunsong. A Study on Architectural Morphogenesis Method Based on Sunlight and Wind Environment [D]. Harbin: Master’s Thesis of Harbin Institute of Technology, 2012:1-3.

In his doctoral dissertation, Zhang Xiangning from Harbin Institute of Technology studied the theoretical foundation, ideological root and technical support for the emergence of complex architectural forms, explained the complex architectural forms' law of "emergent construction, topologized deformation and parametric design", and put forward the application mechanism, operation mechanism and deep interaction of technology in complex architectural form design[26].

Yu Qiong from Tsinghua University discussed the design method of architecture's energy conservation in the protocol stage and unified the parametric design means with the aim of energy conservation in the protocol stage, and studied to establish the building energy efficiency design tool "Most Energy-saving Building Scheme Generating Program MEESG" in the using and protocol stage.

In his doctoral dissertation, Yang Tao from Tianjin University had a detailed study and analysis of the connection between architectural forms and society and science background. The evolution of architectural styles were put into corresponding multi-dimensional perspectives, and macroscopic tool model was constructed to further comprehend the architectural styles, and he also laid a theoretical foundation for the rationality of the emergence of parametric architectural generation[27].

In his master's thesis, Shen Jie from South China University of Technology made use of the architectural performance optimization solver developed on the basis of Grasshopper parametric design platform to optimize the application of passive energy-saving measures in the early protocol stage in a quantitative way[28].

1.2.2 Practical cases at home and abroad

At the same time, design institutions at home and abroad have also developed lots of design practices on architectural morphogenesis based on environmental influence.

Designed by Gensler and cooperated by TJAD, Shanghai Tower is located in the core business district of Lujiazui, Shanghai and becomes the new landmark of Pudong New District of Shanghai. Its surface is a nonstandard hook face, with spirals based on the form unit of the round triangle. In the design process, it adopts dynamic data drawing list to optimize and design the single-deck area and room arrangement, and

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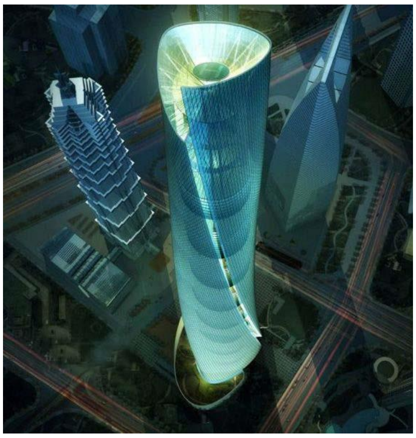
[26]. Zhang Xiangning. Science Dynamics of Architectural Aromorphosis [D]. Harbin: Doctoral Dissertation of Harbin Institute of Technology. 2009:36-53

[27]. Yang Tao. Science Dynamics of Architectural Aromorphosis. [D]. Tianjin: Doctoral Dissertation of Tianjin University.2011:1-5

[28]. Shen Jie. An Applied Research on Technical Analysis Method based on Grasshopper [D]. Guangzhou: Master's Thesis of South China University of Technology. 2012:1-14

carries out simulation analysis and optimization of the floor's rotation angle according to wind load. Parametric design is done on the connection part between the surfaces of the double layers by using BIM platform so as to guarantee the smooth information access in the design process.



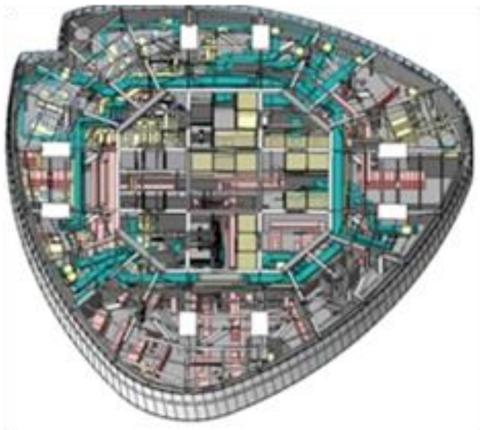


Chart 1-7 BIM Model of Shanghai Tower [29].

Designed by B.I.G office, the project of Astana National Library of Kazakhstan makes use of the grid sunlight data analyzed by Ecotect to confirm the window position and size.

In the project of London City Hall designed by Norman Forster, in order to reach the purpose of minimum direct solar radiation, the building takes sunlight angle as optimized parameter to design a scheme of overall incline to the south, making the building's mass exposed to the sun covered under its own shadow.

Atlier L+ is in the project of Shandong Dongying Cultural Center. According to the requirement of linear laminating arrangement of multiple functions, parametric method is used to generate an architectural form based on Mobius band under the limitations of the given volume of the functive. Besides, according to sunshine conditions, the surface window position and size is confirmed and according to the sunlight direction of surface's subdivided grid, its local lifting angle is optimized.

Designed by XWG Studio, Yunnan Literature Garden is an entire piece constituted by the basic architectural units in the form of courtyard, and four parts including art gallery, literature museum, arts faculty and artists' home are included, and finally it achieves unification through the overall surface optimized by sunlight.

Designed by HDD Fun, Yujiabao Temporary Command Center is designed on its

[29]. http://live.kankanews.com/kkcp/2013-07-31/0013301172_3.shtml.

surface according to different functional spaces' requirements of sunlight and opening degree in the building. Parametric method is used to create an effect of smooth gradual change, which helps realize the unity of beauty and function.

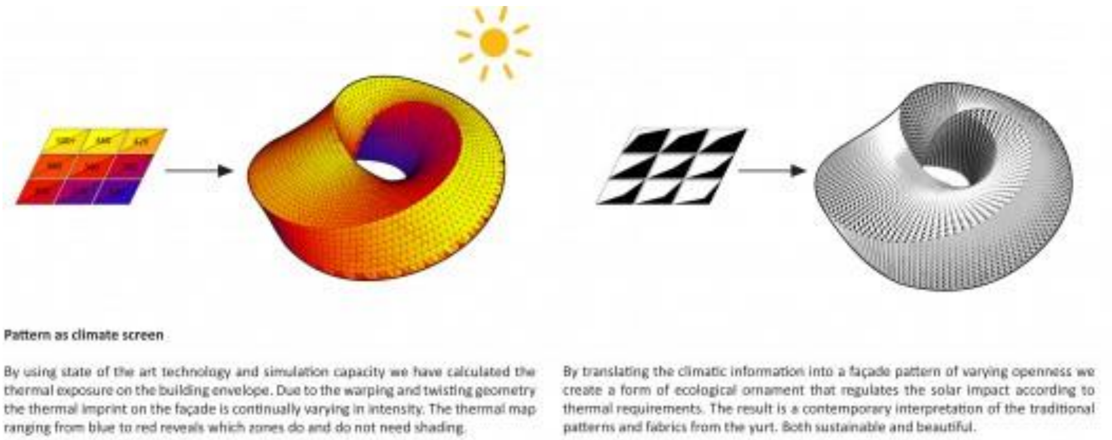


Chart 1-8 Ecological Surface of Astana National Library[30].

It can be found that architectural morphogenesis method based on environmental and ecological performance has become a hot issue in the study of architectural morphogenesis at home and abroad. In terms of the studies in this field overseas, most of them center on solar radiation, light environment and wind environment, and discuss architectural morphogenesis process by combining the quantitative method with the qualitative method. At the same time, based on parametric programming platform, ecological performance simulation platform and the third-party information interaction platform, they try to realize the delivery and response of information data as well as the generation of the design plan. All these studies and explorations have well discussed the possibility of combining parametric design with architecture's ecological performance simulation, but there are still some limitations, such as simple experiment logic, overly ideal experiment conditions and lack of integrality in the design flow. What's more, there hasn't been any design method frame with practical promotion significance and relevant studies under the circumstance of the combined action of multiple environmental factors.

[30]. http://www.archdaily.com/33238/national-library-in-astana-kazakhstan-big/.

Chart 1-9 Bidding Project of Shandong Dongying Cultural Center[31]

At home, studies on architectural morphogenesis method have achieved certain practical outcome, but there are still some problems. Firstly, there is a lack of the usage and research on relevant technology platforms, and there is not enough necessary technical and skill reserve. Secondly, studies at home mainly center on the optimization of the regional part of buildings, and lack the grasp and exploration on the integrality of the design process. Lastly, relevant researches at home mainly focus on analyzing or referring to examples overseas, and it is insufficient in the exploration of applied researches on systematic design procedures.

1.3 Research objectives, contents and method

1.3.1 Research contents and objectives

The thesis raises the following aspects as the basic objectives of the research.

(1) Rationality: The research result is rational in theoretical logic;

(2) Validity: The research result can rapidly and validly assist architectural design;

(3) Ease of use: The research result can be used without fussy operating steps and deep software knowledge

(4) Continuation: continuous transmission among different design and analysis platforms and software can be maintained, operational procedures should be fluent and information loss must be avoided in the linkage of different subjects and design stages.

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[31]. Atlier L+, 2013..

(5) Opening: The system of the design method must be open, which means users can modify, add or reduce certain items according to self needs so as to accommodate to the demands of specific design goals.

Starting from sunlight, wind environment and users' experience, combined with architecture's ecological performance simulation evaluation platform and parametric quadratic programming, the thesis makes use of parametric design programming platform to put forward an integrated ecological architecture's parametric design method aiming at the initial stage of the project. Meanwhile, it is verified in specific design examples, and it also gives a detailed description of the combination of parametric design and architecture's ecological design from the perspective of design application.

The thesis is divided into five chapters. In the introduction part, it gives a brief description of the definitions, interrelations and background of architectural morphogenesis, parametric design and ecological architecture, and it also introduces relevant research and practice at home and abroad, and then defines the research contents and method. In Chapter 2, it analyzes the theoretical foundation and accomplishing means of architectural morphogenesis under the influence of ecological performance. Furthermore, in Chapter 3, it puts forwards the process frame of ecological shaping design method, and expounds its definition, constituent parts, operation procedures and key issues. In Chapter 4, combined with specific design cases, it has a global practical application of the generation logic and optimization logic in the process frame. In the end, in Chapter 5, it summarizes the advantages and disadvantages of the parametric architectural design method based on ecological shaping, offers possible optimization solutions and shows some expectations on the development trend of this design method.

1.3.2 Research method

(1) Document analysis method: by going through the existing documents at home and abroad, the thesis learns about the research trends of the following three aspects: architectural morphogenesis, parametric design and ecological environment simulation. Firstly, with the keywords "architecture", "morphogenesis" "parametric" and "environmental simulation", the author searches Chinese literature database including Wanf and CNKI so as to grasp the domestic research conditions. And then with the keywords "Performance-Driven", "Parametric Design" and "Environment Simulation",

the author searches relevant SCI magazine and thesis, EI conference papers and PQDT-foreign degree papers of master and doctor to master the overseas research conditions. In the last step, the literature is entangled according to keywords, so as to discover and expand outcomes related to the research topic and target.

(2) Interdisciplinary method: Because the research involves multiple fields including building science, social science, computer science and environmental science, based on the analysis of integrating relevant studies of all subjects, the thesis tries to form a wide but focused cross point so as to have a theoretical analysis investigation.

(3) Case study: the author collects, analyzes and studies relevant building and design cases at home and abroad, and reads relevant theoretical documents; cases according to thesis requirements and having huge value will be investigated on the spot so as to obtain direct cognition and experience.

(4) Combination of qualitative and quantitative analysis: On the one hand, by deduction and analysis, this research puts forward relevant qualitative analysis conclusion and judges and controls the generation result in advance. On the other hand, in the morphogenesis process, quantitative data will be got to have a quantitative analysis to verify the scientificity and validity of the generative process.

Chapter II. Theoretical Principle and Technical Platform of Parametric Design of Buildings Based on Ecological Shaping

2.1 Theoretical principle

The part of theoretical principle comprises of complex scientific theories, the morphogenesis theory of architectural configuration and performance-driven design theory. The first theory explains the historical background and the root of the second theory, while the second displays its development and application in architecture, and the third supports its realization.

2.1.1 The theory of complexity science

The complexity science, as an emerging research category, features reductionism, studies on complexity systems, centers on interpreting operational patterns of complexity systems and aims to enhance people's capacity to know, explore and transform the world.

Simplicity has been long regarded as an ancient creed in the scientific field. People used to interpret phenomena on the basis of reductionism and simplify what is happening in the world. According to reductionism, all things happened could and should be reduced to "teams" composed by a series of fundamental elements, which are independent and indivisible and the essence of the whole phenomenon could be deduced through studies on the properties of these fundamental elements. Complexity tries to cover the simple essence of what happened and the key task of scientific researches is to reveal the order pattern covered by exterior chaos[32]. From this point of view, time and space are regarded as linear, independent and partial, and the sum of parts is equivalent to the property of the final main part. Proposed by French philosopher Decare, supplemented and developed by scientists such as Newton and Einstein, reductionism has gone through the examination and improvement of scientific practices lasting for more than 400 years, finally reaching its dominant role in the scientific system. Thereafter, the greatest goal of science is deemed to summarize facts as many as possible and work out an ideal system that includes least independent

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[32]. 吴彤. 复杂性概念研究及其意义[J]. 中国人民大学学报. 2004, (5): 2-9

hypothesis and axioms through logical deduction under least axioms and hypothesis, thus interpreting the world. [33]

The progress of science and technology during the 20th century, especially the expanding scientific field after the two world wars, has highlighted the shortcomings of classic reductionism. Scientists switched their attention to complexity, and by virtue of the rapid development of research means, they gradually formed and established a new scientific type, namely complexity science. In general, complexity science is criticizes and surpasses reductionism in respect of methodology[34]. It advocates that things are changing constantly and they are connecting with each other, thus making the subordinate system open. Time and space are nonlinear, heterogeneous and nonlocal.

Celebrated French thinker and philosopher Edgar Morin first proposed "complexity methodology" in his book "Lost Pattern: Study on Human Nature" which was published in 1973[35]. According to him, apparent chaos boasts the potential to generate orders, which could be realized by virtue of intermediary elements. The theory negates the mutual repulsion of orderliness and chaos, and points out that the two could transform and promote mutually under certain conditions, thus elevating the organizational complexity of systems, which was later called "dynamic orderliness".

After Edgar Morin, Brussels School led by Ilya Prigogine proposed the concept of "complexity science" in 1979[36]. Opposed to classic science, the theory believes that the world is composed of irreversibility and randomness. What's more, determinism and reversibility pursued by classic science only applies to limited simple conditions. He also points out that the development of quantum mechanics may prove the irreversibility of time and humans live in a determined probability system, which deconstructs a world of determinacy. His theory was named dissipative structure theory and was widely used in the fields of medical science, psychology and biology.

In 1984, Murry Gell-mann took the leading role in organizing US Santa Fe Research Institute, which was later deemed to be the backbone for global complexity study. Its researches center on breaking the inherent boundaries of traditional sciences. In addition, it applies complex responding capacities of the system and the corresponding complex structures to study relevant issues in biology, physics, psychology and computing science.

Complexity is featured by[37]:

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33. 北京大学现代科学与哲学研究中心 编.复杂性新探[M]. 北京:人民出版社, 2007 年 9 月:185
34. 黄欣荣. 复杂性科学的综合集成方法及其意义. 重庆工学院学报(社会科学版). 2009, (5): 91-96
35. 埃德加·莫兰. 迷失的范式, 陈一壮译. 北京:北京大学出版社. 1999:10-25
36. 伊利亚·普利高津. 确定性的终结, 湛敏译. 上海:上海科技教育出版社. 1998:30-47
37. 冷天翔. 复杂性理论视角下的建筑数字化设计[D]. 广州:华南理工大学博士学位论文. 2011:20.

(1) Nonlinear, opposed to the concept of "linear", used to be a mathematic concept, which indicates logical relations of the properties of variables in mathematic forms. Here, it is a systematic theory in terms of methodology. The theory believes that nonlinear is the root why complexity system retains its diversity and unpredictability. According to the theory, the present world is nonlinear in essence. Though its expression and forms vary, linear system is an acceptable rough description of nonlinear system, which is limited by cognitive modes. However, the simplification which abandons the complexity of things will induce inaccurate and false cognitive results.

(2) Nondeterminacy, opposed to determinacy, exists as a negation to determined world depicted by classic natural science led by Newton mechanics. According to classic natural science, the blank of human cognition of the world is temporary and waits to be filled and a complete and accurate recognition to the world will surely show itself someday in the future. Nonetheless, studies on chaos theory in modern systematic science expose the intertwining determinacy and nondeterminacy in the present world.

(3) Self-organization. Self-organization theory, developed since late 1960s, was used to explore the formation and development mechanism of bio-system, social system and other complex systems. Specifically, it indicates the orderly structure of a system and its formation process. Self-organization system is an orderly structure that spares external strength and instructs and goes through the processes of self-regulating and evolution, self-organization, creation and evolution.

(4) Emergence. Emergence, opposed to "additive property", is a scientific concept which depicts multi-leveled presentation of complex systems, structures and features. It advocates that components of the whole system will display the properties, features and functions vacant in the sum when we organize parts in an orderly way. Features displayed will change along with the composing modes of the system, which makes them unpredictable.

2.1.2 Morphogenesis Theory

The development of complexity science offers people a chance to know the self-organization pattern of individual objective elements in the world, thus promoting the development of morphogenesis theory in the architectural field and pushing forward the transform of top-down decision mode to down-top in respect of architectural form creation.

Morphogenesis is a process to compose elements of architectural forms by following a certain organizing logics, take shape through self-organization and generate architectural forms. Philosophic thinking of Gilles Deleuze, representative philosopher of post-structuralism in France, lays foundation for the development and promotion of morphogenesis theory later on.

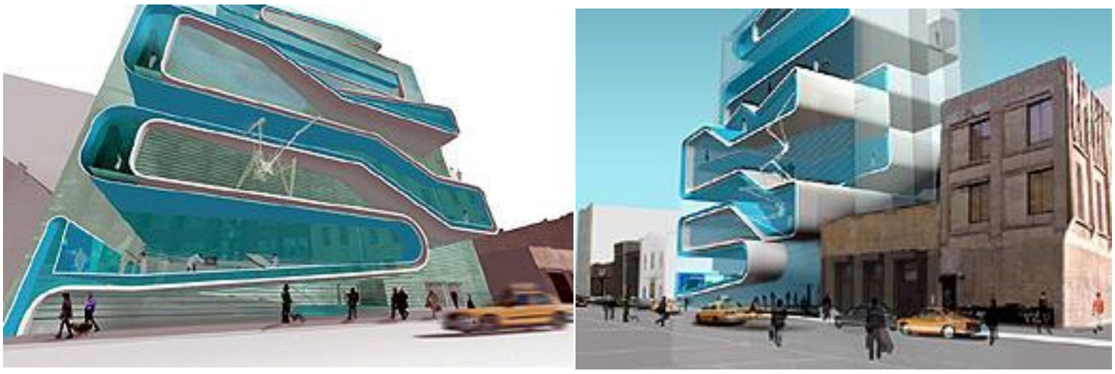
Prior to post-structuralism, western ideological systems are constructed on the basis of being and identity, while Deleuze emphasizes difference and becoming[38]. It overturns dichotomy concerning world pattern in Plato philosophy and the deriving western philosophies. According to his philosophy, “becoming” is the sole status beyond “being” of all things in the universe while “being”, which is highlighted as the essence and objective of “becoming” in Plato Philosophy, is just a relatively stable instant in universal becoming. What we see and feel is the essence of the world,

38. 麦永雄. 德勒兹与当代性一一西方后结构主义思潮研究[M]. 桂林:广西师范大学出版社, 2007:7

and the so-called world of ideas hidden behind phenomena actually does not exist.[39]

What Deleuze advocates are instantaneousness and contingency, and he opposes centralization, regularization and integration. Such a philosophy inspires architects who conduct wide practices based on it. Theoretical concepts proposed by Deleuze include:

(1) Fold[40]. As the core concept of Deleuze philosophy, it derives from monadism of Leibnitz philosophy. Leibnitz proposes that substance is a bent and elastic continuum which is composed of ever-segmenting folds rather than disjunctive particles in traditional sense. It can be segmented endlessly and though folds get smaller, substances will never be dissolved to points or ultimacy. The smallest element of material unity is



Graphic 2-1 draft of Diller-Scofido Eyebeam Atelier Museum of Art and Technology[42]

fold, rather than point, which is never a part, but an extreme of lines[41]. Such a theory points out that materials do not differentiate in terms of external and internal parts, however, they are generated by dual folds. Time and space coexist in material folding and the exterior incarnates its organization.

Completed buildings show that the application of fold theory lies in three aspects: one is monomer fold. For example, in the scheme of Eyebeam Atelier Museum of Art and Technology, architects Diller and Scofido separate work areas and exhibition areas with a ribbon space. Ribbon folds and rises constantly, taking the role as roof, floor and wall. The ribbon space stores pipelines in the building. The second is the turnover of internal and external of the building, such as the frequently-used design prototype of Mobius Band. Similar to the design of Mercedes-Benz Museum of UN Studio, exhibition halls are connected by several Mobius bands, forming a set of coherent touring lines. The third is to regard building as landscape.

[39]. 姜宇辉. 德勒兹身体美学研究[M]. 上海:华东师范大学印刷厂, 2007:8
[40]. 德勒兹. 福柯·褶子[M]. 于智奇,杨洁译. 长沙: 湖南文艺出版: 2001:334
[41]. Gilles Deleuze. The Fold: Leibniz and the Baroque. University of Minnesota Press. 1992: 11-13, 19-21
[42]. http://www.arcspace.com/features/diller-scofidio--renfro/eyebeam/

Graphic 2-2 Mercedes-Benz Museum Designed by UN Studio[43]

(2) Smooth. Smoothness, highlighting continuous development and change of forms, integrates heterogeneous elements into a system while retaining heir heterogeneity. It is an ideology against the thinking pattern of totality, hierarchy and linear. In respect of special concept, it indicates the dissolving of principal-subordinate awareness and the accumulation of adjacent elements which could not be divided by number or dimension[45]. In architecture, Rego Lynn put forward the concept of Blob, which underlines the vivid and blurry relations between the whole and partial buildings. When two Metaballs meet, they will connect smoothly and form a new blob while remaining features of parts that do not cross.

Graphic 2-3 Beijing Galaxy Soho designed by Zaha Hadid Office[44]

(3) Diagram. According to Deleuze, the concept of diagram, as a translating machine between functional demands and abstract forms, dissolves the opposition between materials and forms, thoughts and words. It abandons the intermediary of languages and emphasizes the interpretation of phenomenon itself, thus making it

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[43]. http://www.arcspace.com/features/diller-scofidio--renfro/eyebeam/

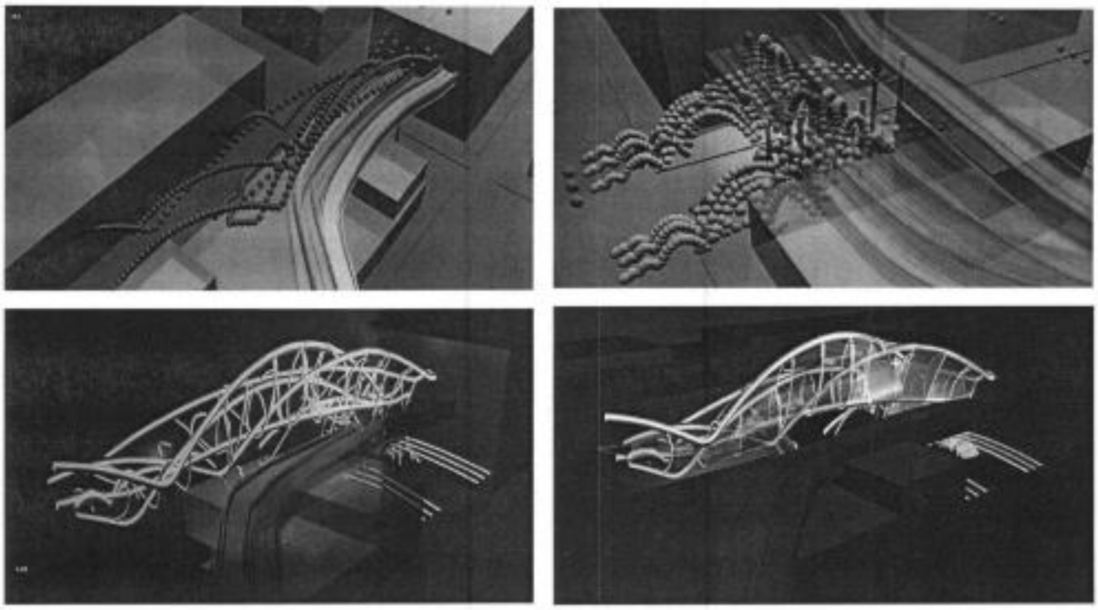
[44]. http://galaxysoho.sohochina.com/

[45]. Gilles Deleuze. A Thousand Plateaus: Capitalism and Schizophrenia. University of Minnesota Press. 1987: 43-45, 67-68.

abstract yet concrete, simple yet profound.[46]

(4) Becoming. In Deleuze philosophy, becoming is the prime property of matters. “becoming” indicates re-organization of various “strengths” in the field. All parts take synergistic effects in the process, thus promoting the new unification. The process is not determined by the prime condition of matters and does not include analysis and answers questions such as “what is the final form”. In this regard, it will not stimulate or reproduce inherent forms.[47]

In the Port Authority Getway contest scheme of Greg Lynn, all elements in the field are included as “strengths” to create architectural forms. In addition, they are simulated as moving particles with the help of software. In this regard, a series of related strengths are intertwined, which guarantees the variety of schemes in the becoming process as well as the smoothness of the logical process, so that the scheme will not sacrifice its potentials to achieve the final “unity”.



Graphic 2-4 Port Authority Getway contest scheme of Greg Lynn[48]

In summary, the most direct impact on architectural creation brought by Deleuze philosophy lies in the transformation from inflexible and static architectural designing as “result” to dynamic and complex becoming logics as “process”. The traditional designing process of pursuing the only and determined answer has been replaced by self-organizing designing featured by pursuit of proper logics. Based on such a theory, modern architects are able to work beyond traditional static and inflexible view of time

46. 麦永雄. 光滑空间与块茎思维:德勒兹的数字媒介诗学. 文艺研究. 2007, (12): 76-84
47. Charles J. Stivale. Gilles Deleuze: Key Concepts. McGill-Queen's University Press. 2005:12
48. Greg Lynn, Animate Form[M], New York: Princeton Architecture Press, 1988。

and space. Buildings are integrated in the diachronic process of human, society and environment, all of which interact with each other. Architect Ben van Berkel from UN Studio points out that what matters in the reciprocating motion of architecture, engineering, movement, public areas and individual imagination are the established relations among these members rather than concrete creation. Such relations could be applied as parameters in the design and become architectural elements that could be developed and designed, thus making architectural morphogenesis more rational and exercisable.[49]

2.1.3 Performance-driven Design Theory

Being a crucial branch of designing theories, performance-driven designing covers subjects such as industrial designing, architectural designing and product designing. It aims to enhance the ultimate performance of designed projects by virtue of analysis tools and work out various designing solutions as well as choose the best while satisfying its functional demands. “Performance” here does not boast a fixed definition. According to Ullman, performance is the measurement of product behavior and function[50]. Kalay defines it as a value to measure the problem-solving capacity of a particular product[51]. Performance-driven designing theory is proficient in improving design rationality and efficiency, which activates its application in the area of architectural designing. Performance-driven architectural designing attaches importance to improving performance of architectures, takes full account of surroundings, climate conditions and function needs, pursues comfort, sets foot on digital designing platform, designate and implement corresponding designing strategies. Performance, as the sole evaluation criterion, is controlled subjective top-down outcomes. In the meanwhile, contrary to the down-top self-organizing process, it optimizes and filters outcomes, adjusts and balances influencing factors and finally reaches the designing goal of ultimate performance.

After introducing performance-driven designing, a series of problems in architectural designing process have been optimized and solved. For example, along with the ever-deepening labor division in architectural designing, knowledge and operations in disciplines such as architectural physics and structural engineering, which were closely related to designing, have been exercised by engineers with certain

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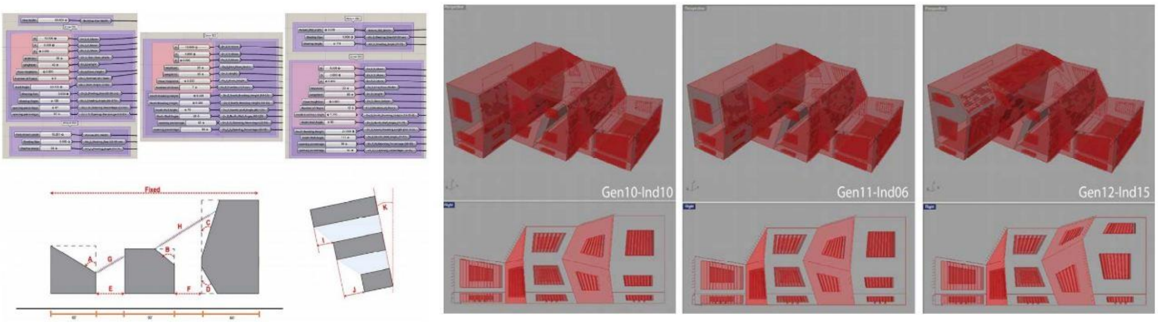
49. 田宏. 数码时代“非标准”建筑思想的产生与发展[D]. 清华大学硕士学位论文. 2005: 4-7, 9, 1, 17, 21, 32, 36~38, 8
50. Ullman D G. The Mechanical Design Process [M]. New York: McGraw-Hill, 2002: 25-29.
51. Kalay Y E. Performance-based Design [J]. Automation in Construction, 1999, 8(3): 395-409.

expertise. It demands higher professional level of designing outcomes and also highlights the insufficiency of architects in mastering relevant knowledge, which is the reason why consideration to physical and mechanical property gets weaker gradually at the earlier stage of architectural designing. By virtue of the combination of performance evaluation and designing process, the performance-driven mechanism promotes communication and sharing of data information among different subjects, which fills the gap between them to some extent. In addition, performance-driven designing mechanism, based on digital performance stimulation platform, takes the data computing capacity into full play, which covers the shortage of human brains in bulk data processing during the designing process and provides favorable technological support for the analysis and execution of designing strategies.

In respect of application, Franca Trubiano from University of Pennsylvania put forward and implemented an architectural morphogenesis system driven by thermal performance and illumination performance, which is applied to determine forms in the early period of scheme designing. While generating numerous schemes according to the set layers, height and areas of each floor of buildings, we follow the performance-driven optimizing search engines and designed evaluation criterion, and automatically choose an architectural form which measures up the criterion by the program, thus realizing the architectural scheme generation and optimizing driven by performance. [52]



Graphic 2-5 Office Building Design Based on Thermal Performance and Illumination Performance[53]

2.2 Technical Platform

2.2.1 Geometric Modeling Platform-Rhinoceros

[52]. Franca·Trubiano. Building Simulation and Rvolutionary Optimization in the Conceptual Design of a High Performance Office Building. 13th Conference of International Building Performance Simulation Association. France. 2013:August 26-28

[53]. http://www.ibpsa.org/proceedings/BS2013/p_1449.pdf

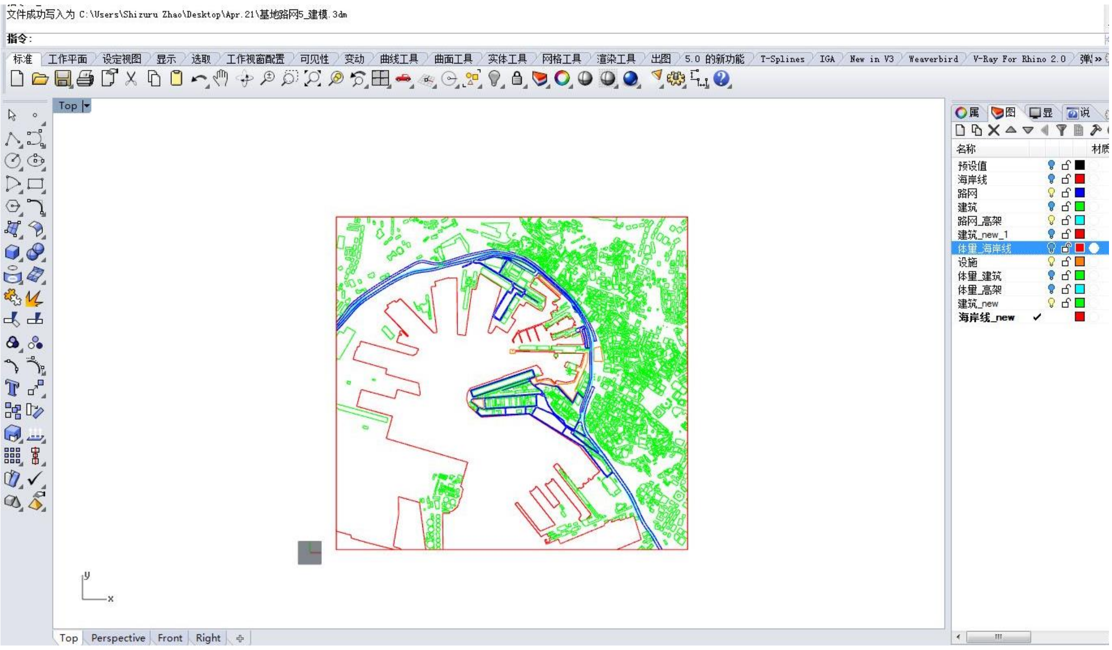
Rhinoceros, short for Rhino, is a widely used 3D modeling software. Sold by Robert McNeel & Associates in 1998, it was able to manufacture models needed for constructions, analysis evaluation, product generation and animations based on surface editing and generation modes of Nurbs graphic techniques. Owing to its excellent editing and modeling capacity and since that architectural forms generated under the influence of sunlight and wind environment are featured by non-standard geometric patterns, it is chosen as the primary modeling platform.

Graphic 2-6 Rhinoceros and Nurbs Surface Editing[54]

In the meanwhile, thanks to its open platform designing, Rhino boasts numerous extensions, including Grasshopper, Python, Rhino script and other parametric extensional platforms, which may fully exert its advantages in compatibility and techniques in respect of parametric design.

In addition, its favorable data compatibility ensures data transmission among various platforms during the research process, and more than 30 mainstream document formats such as .dwg .skp .3ds .dae could be stored.

[54]. http://www.rhino3d.com/



Graphic 2-7 Rhinoceros Modeling Interface

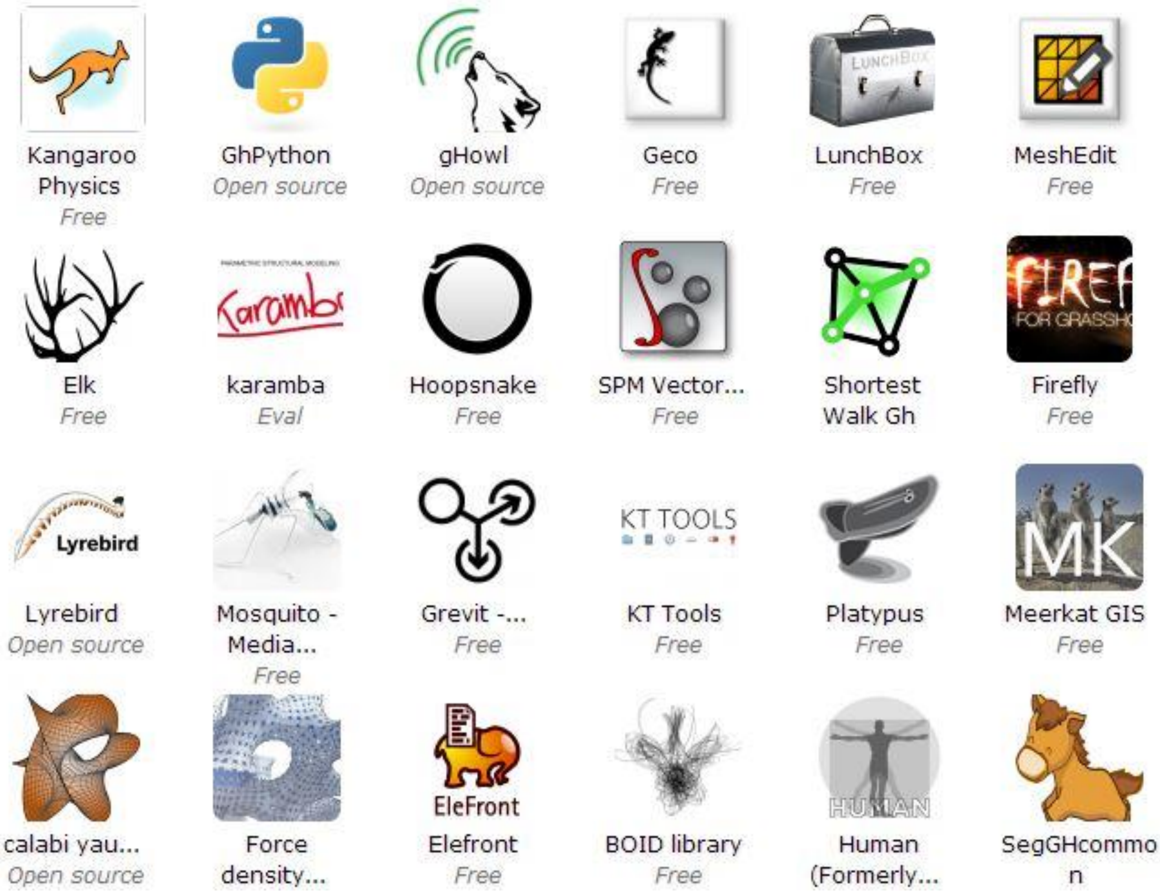
Rhino program applied in the present study is Rhino 5 SR8 64 bits, which went public on March 11, 2014 and is by now the latest official version.

2.2.2 Parametric Programming Platform-Grasshopper

As visualization programming plug-in developed by MaNeel Company, Grasshopper and Rhinoceros are perfectly compatible. Different from Rhino script and Python, Grasshopper initiated the application of “battery pack” to replace traditional instruction input operations. Each battery pack is the assemblage of one or several simple program instructions, which edits and implements complex functional programs through the integration of different batteries. It makes the whole programming process more perceivable, clearer in logic arrangement and easier for Debug and program error recovery. At the same time, since it spares the utilization of obscure programming languages, first utilization of it becomes much easier, which makes it possible for rapid expansion and promotion. As a result, it has become the most widely used and scattered programming platform for parametric designing.

In the meanwhile, Grasshopper expands well. By virtue of numerous function expansion plug-in units designed for it, we can realize multiple powerful expansion functions such as ELK, Kangaroo and Geometry GYM. At the same time, expansion plug-in units can be used to exchange data information with almost all mainstream modeling software at present, thus improving work efficiency and expanding boundaries of designing research. In the present study, data exchange between geometric data on 3D modeling platform and performance simulation platform is realized through Geco plug-in unit on the platform. Geco makes it possible for Rhino and Ecotect performance analysis software to implement real-time data exchange and set up model, which is the circular work flow of analysis model, thus activating environmental data generation.

Graphic 2-8 Launching Interface of Grasshopper[55]



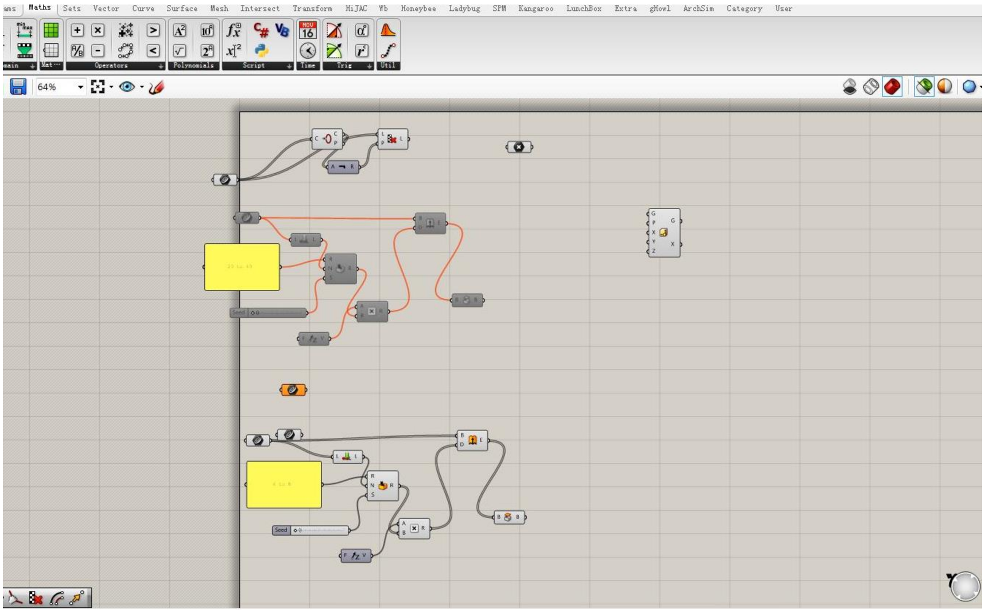
Graphic 2-9 Part of Grasshopper Plug-in Units[56]

Parametric designing is confronted with complex geometric forms bearing bulk

55. http://www.grasshopper3d.com/
56. http://www.food4rhino.com/

data. For the purpose of accurate editing operations, we need to maintain and conduct data structure in each procedure. Boasting a favorable data tree structure that meets such a demand, Grasshopper is able to locate and store bulk data in a unit of “path”, thus ensuring the accuracy and efficiency of internal data conducting.

The core of Grasshopper lies in its parametric modeling technology. By virtue of definition to form response logic on Grasshopper platform and modification of program input variables, designers are able to modify and update geometric information on 3D modeling platform. Each step is taken on the basis of transmission of parameters constituting geometric forms and their parts. The meta-information of all graph, as a part of the parameter generation procedure, is related before being “baked” (Bake, a particular name for program operation, refers to data transmission from Grasshopper to modeling platforms for the purpose of further edit and modification) to Rhino. The association disappears when the information is baked to the modeling program.



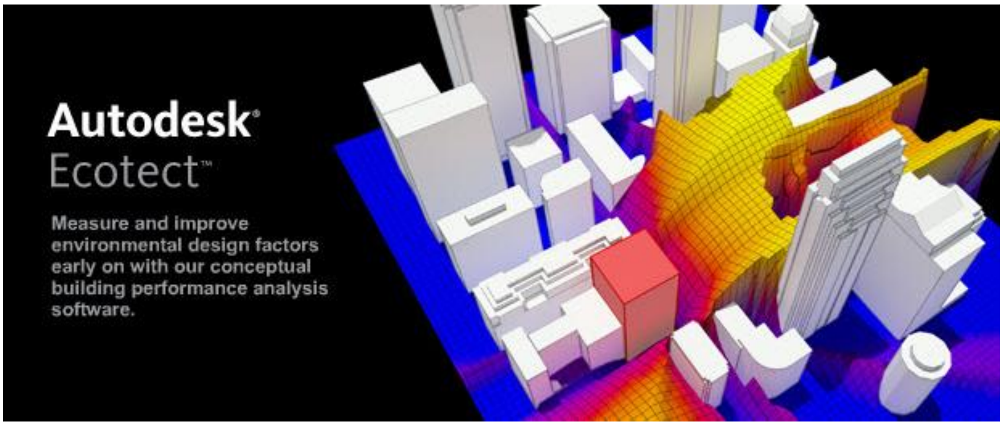
Graph 2-10 Operating Interface of Grasshopper

2.2.3 Performance Simulation Platform-Ecotect and Winair

	Ecotect	Radiance	Energyplus	DEST	Equest	Vasari
易用性	✔✔✔✔	✔✔	✔	✔✔	✔✔✔	✔✔✔✔✔
兼容性	✔✔✔✔✔	✔✔	✔	✔✔	✔✔	✔✔✔
热环境	✔✔✔	✔✔✔✔	✔✔✔✔✔	✔✔✔✔	✔✔✔✔✔	✔✔✔
光环境	✔✔✔✔✔	✔✔✔✔✔				✔✔✔
声环境	✔✔✔✔✔					
日照	✔✔✔✔✔	✔✔✔				✔✔✔
风环境	✔✔					✔✔✔✔✔
✔：差，✔✔：较差，✔✔✔：一般，✔✔✔✔：较好，✔✔✔✔✔：非常好，空白表示无此功能						

Graph 2-12 Comparison of Ecotect and other Performance Analysis Software[57]

Ecotect, green software for architectural analysis developed by Autodest Company, applies to all links from conceptual designing to detail designing. It covers widely used simulation and analysis functions. The first edition showed up in 1997, and after over ten years of development, it is mature and widely used globally now.



Graph 2-11 Ecotect

With visualized operation and analysis interface, the software is able to present the ultimate result with direct graph. In addition, its progressive data input makes it possible to implement explorative architectural performance tests while designing information is not accurate in the early stage of scheming, which better directs scheme designing. Since the primary stage is crucial to the whole scheme designing process[58], its advantage gets more important. For example, sunlight radiant performance analysis model only needs basic geometric information and the local meteorological statistics of the building. With no information concerning particular materials and the construction details, sunlight radiant intensity could be calculated according to sun orbit and sunlight intensity of the sample parts. In addition, the analyzing results can be stored and derived

57. Wilde P.D., Voorden M.V.D. Computational support for selection of energy saving building [M]. Eighth International IBPSA Conference. Netherlands. 2004: 1409-1416
58. http://usa.autodesk.com/ecotect-analysis/

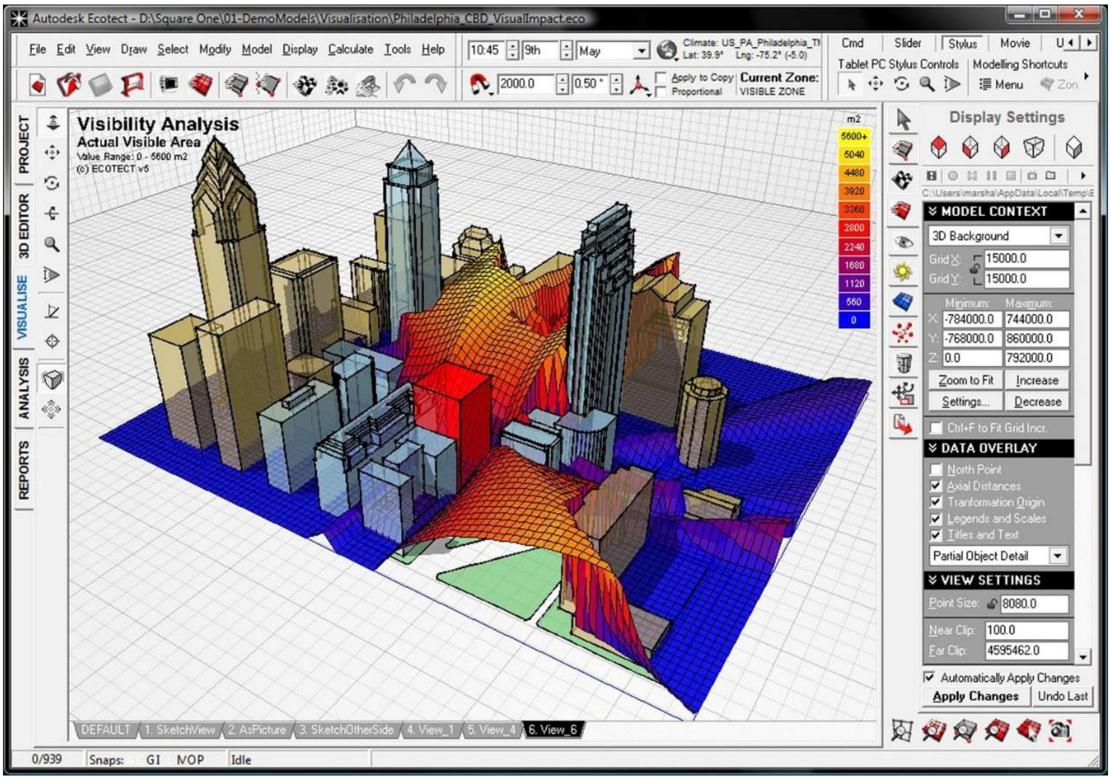
easily.

Secondly, it boasts integrated analysis engines, which makes it possible to coordinate various analysis engines such as sunlight radiation and acoustic wave particles while inputting a group of modeling data, thus easing the workload.

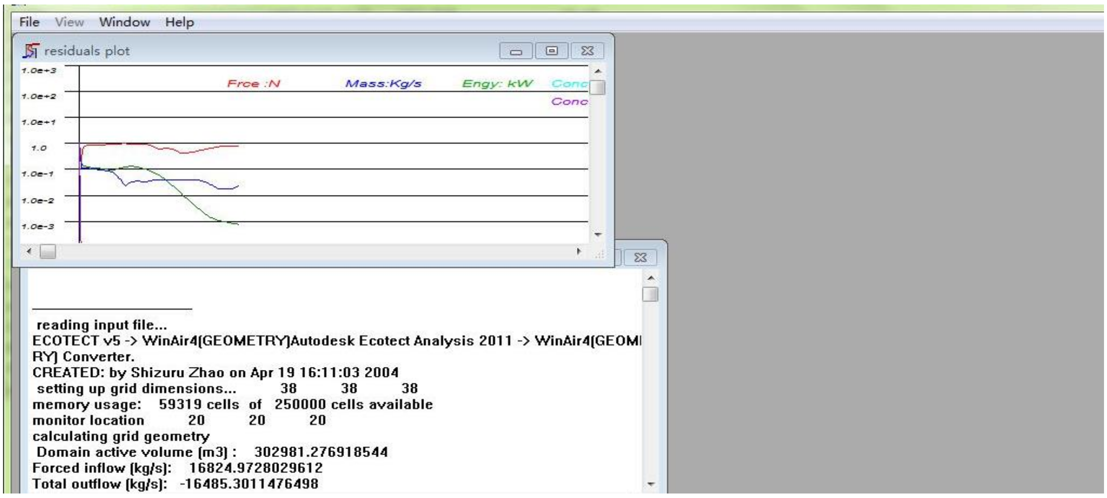
In the meanwhile, Ecotect, featured by favorable data compatibility, may exchange data on multiple platforms and in various document formats, and it provides excellent technical support for the present research.

Last but not least, irrespective of the fact that Ecotect bears low accuracy in simulation, what the present study values is an environment-based architectural designing method, with a focus on detecting logical relations among data and studying how it directs designing. In this regard, limitation of its data accuracy will not impact studies on the methodology.

It is worth mentioning that the wind environment simulation software chosen in the present study is Winair, an Escotect based CFD functional expansion plug-in unit, which is perfectly compatible with Ecotect. The analysis results can be imported to Ecotect and presented in the form of graph or data. Then, they will be exported to Grasshopper from Ecotect, so that the wind environment may drive the generation process of architectural forms.



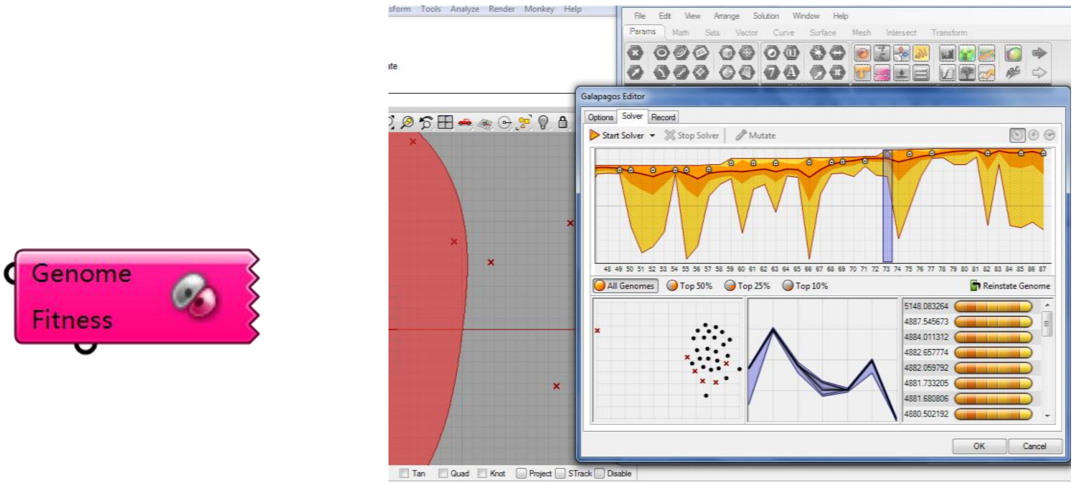
Graph 2-13 Operational Interface of Ecotect



Graph 2-14 Computing Interface of Winair

2.2.4 Optimum Platform for Genetic Algorithm-Galapagos

Genetic Algorithm, as a self-adaption global optimal algorithm based on Darwin’s theory of evolution, centers on simulating biological evolution. By introducing concepts such as breeding, hybridization, mutation, competition and selection, it transcends traditional methods which are featured by difficult mutation, long-time searching and easy local extremum. The optimal solution can be achieved through maintaining a set of feasible solution, which could be re-organized and improved in respect of its moving paths or trends. [59]



Graph 2-15 Computing Interface of Galapagos

Genetic Algorithm has the following advantages:

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59. Zhou Ming, Sun Shudong. Principle and Application of Genetic Algorithm [M]. Beijing: National Defense Industrial Press, 1999:25-30

(1) Genetic Algorithm takes a set of feasible solution rather than individual ones as the operational objective; it has multiple searching paths rather than a single one, so that it may concur easily.

(2) Genetic Algorithm utilizes only the value information of object functions, not high-order information such as gradients, so that it is applied universally in large-scale and nonlinear multimodal functions as well as object functions with no analytic expressions.

(4) The preferential mechanism of genetic algorithm is a "soft" decision. Combined with its favorable concurrence, it boasts the advantages of global optimization and stability.

(4) Feasible solutions operated by genetic algorithm are encoded. Object functions can be interpreted as adaptive values of codified individuals (feasible solutions), which makes it simple and operable.

Optimization of possible function solutions can be described by the following mathematical model: [60]

$$\begin{cases} Maxf(x) \\ s.t. X \in R \\ R \subset U \end{cases}$$

In formula 2-1, X=[x1,x2,…,xn]$^{\tau}$ is the decision variable, f(x) is the object function, the second and third equations are constraint conditions, U is the basic space and R is one subaggregate of U. The solution X meeting constraint conditions is called feasible solution. Set R contains all solutions meeting constraint conditions, which can be called feasible solution set. In genetic algorithm, n-dimension variables X=[x1,x2,…,xn]$^{\tau}$ can be expressed by a symbol string X composed by Xi(i=1,2,…,n).

$$\mathrm{X} = \mathrm{X}_1\mathrm{X}_2 \cdots \mathrm{X}_n \rightarrow \mathrm{X} = [x_1, x_2, \cdots x_n]$$

Each X_i is deemed to be a gene, whose possible values are called allelic genes. As a result, X is regarded as a chromosome composed by n genes. The arrangement pattern X formed by such coding is the genotype of individuals, and the corresponding X is the phenotype of individuals. Chromosome X can be called individual X, whose adaption degree is determined by certain rules. Individual adaption degree is associated to object functions of individual phenotype. The closer of X to the optimal point of object

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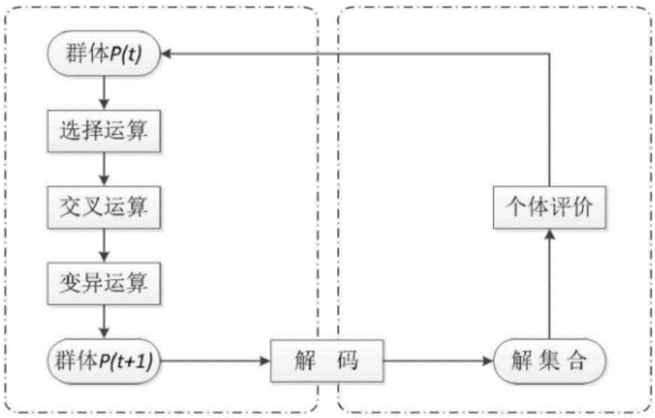
[60]. Zhou Ming, Sun Shudong. Principle and Application of Genetic Algorithm [M]. Beijing: National Defense Industrial Press, 1999:40-57

function is, the higher its adaption degree becomes, and vice versa. In genetic algorithm, the decisive variable X comprises the solution spaces of problems. Searching for optimal solutions of problems is conducted by searching for chromosome X. In this regard, all chromosomes X form the searching space for problems. Operand of genetic algorithm is a set composed of M individuals. Similar to the natural evolution process of living things, the operational process of genetic algorithm is repeated. The t-generation group is P(t), and after a generation of inheritance and evolution, we get the t+1 generation called P(t+1), which is also a set of several individuals. Going through the process of inheritance and evolution constantly, the set always inherits individuals with higher adaption degree to the next generation. As a result, a favorable individual X is generated among the set, whose phenotype X^{92} will reach or get close to the optimal solution X. [61]



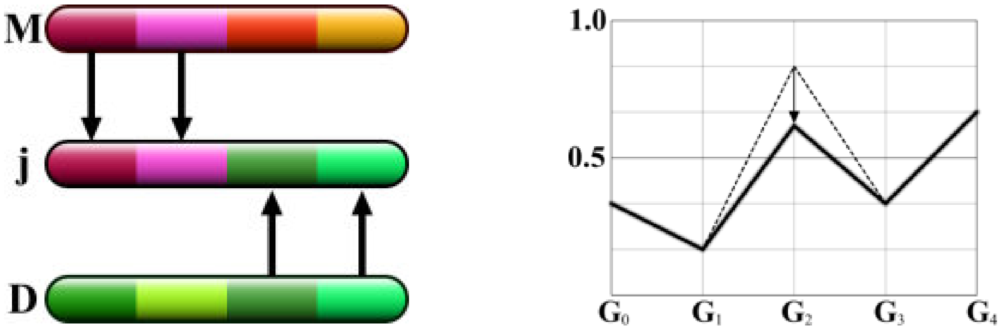
Graph 2-15 Computing Process of Genetic Algorithm

In the meanwhile, in order to improve the genetic diversity of the evolutionary set, we add genetic crossover and chromosome disorder to the searching process, apply genetic operator to set P(t), and carry out the following operations based on adaption degree selection:

(1) Crossover: matching two individuals in set P(t) to exchange their chromosome X_i with a certain probability.

(2) Mutation: replacing one or several genetic values for each individual in the set P(t) with a certain probability to get the value of allelic genes.

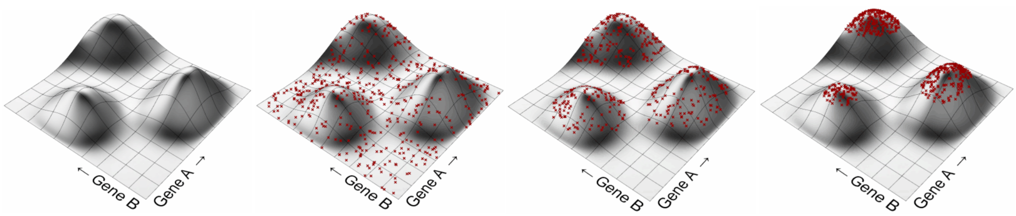
[61]. Zhou Ming, Sun Shudong. Principle and Application of Genetic Algorithm [M]. Beijing: National Defense Industrial Press, 1999:58



Graph 2-16 Gene exchange and Gene Mutation of Genetic Iteration[62]

Galapagos arithmetic device, realizing iteration optimal selection in Grasshopper as an indispensable link in the automatic optimization process, plays a crucial role in the present study. With a convenient man-machine interface and easy operational system, it has no restriction on problems to be solved. Theoretically, problems in all procedures can be solved with a set of independent variable and dependent variable.

In the present study, Galapagos has achieved anticipated results in optimal searching of architectural form feedback under environmental influences and evolutionary operation on large-scale complex data sets.



Graph 2-17 Demonstration of Galapagos Genetic Algorithm Optimal Searching[63]

[62]. http://www.grasshopper3d.com/profiles/blogs/evolutionary-principles
[63]. http://www.grasshopper3d.com/profiles/blogs/evolutionary-principles

Chapter III Logical Framework of Parametric Design of Buildings Based on Ecological Shaping

The framework of parametric design of buildings based on ecological shaping comprises shape generation and shape optimization, both of which cover dozens of diversified base level procedures in addition to such three upper level procedures as logical formulation, controlling program writing and procedure execution. Shape generation is a process of analyzing and refining task requirements, designing concept and environmental factors, transforming to mathematical logic and growth parameters on computer platforms, executing them and finally reaching the generated results. Shape optimization, however, refers to a process of analyzing and improving generated results according to ultimate designing expectations and goals, and then exerting influence on growth parameters in reverse. The two collaborate in all designing phases and exchange data at appropriate times, thus realizing the combination of the down-top generation of architectural forms influenced by environmental factors and the top-down controlling over designing results as required.

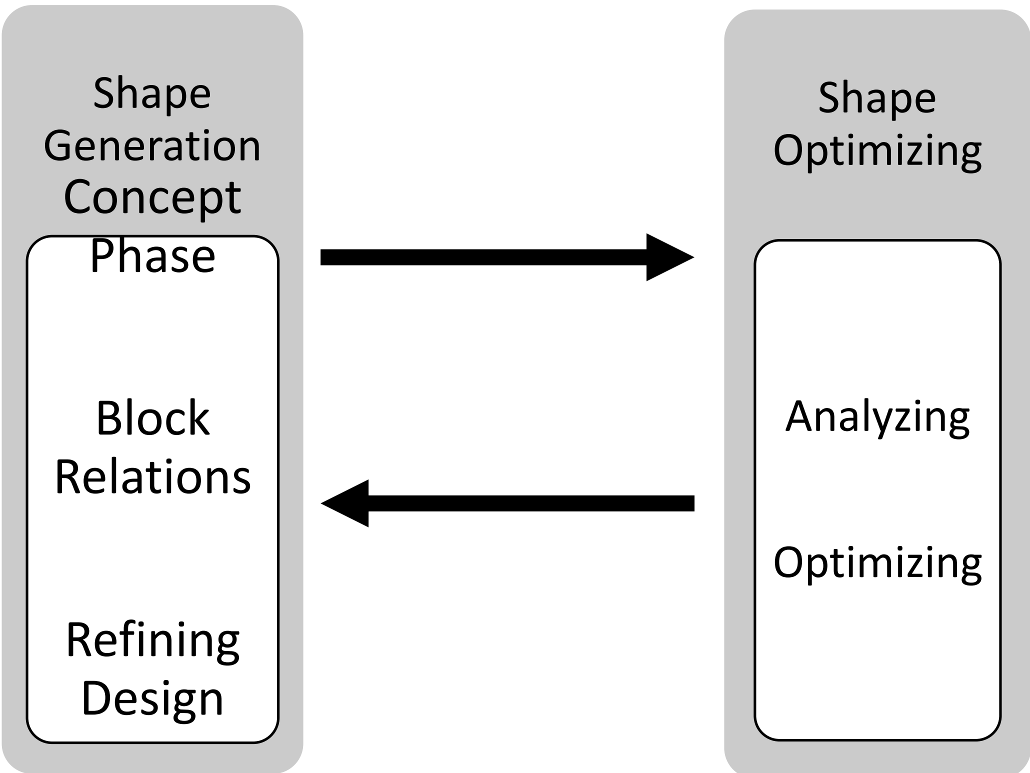


Chart 3-1 Sketch of interaction between shape generation and shape optimization

It is notable that the three sub-procedures logical formulation, controlling program writing and procedure execution in each main procedure of shape generation and optimization are featured by the linear top-down relation inside the procedure boundaries. However, data exchange is necessary for each procedure and parallel procedures outside its program boundaries under certain conditions or requirements. In such a system, the logical formulation procedure gives high priority to the definition of system operation models, and controlling program writing procedure emphasizes the constitution of system models, which is an important preparation phase for architectural shape generation system. Procedure execution serves the architectural shape self-organizing generation influenced by environmental information under generation logic. It highlights the application of the generation system, which is the end feedback phase of the framework system.

The procedure framework summarizes application programs of parametric design based on ecological shaping as its logical guide for realization and application. By virtue of the application background, dynamic relations and internal operating procedures and methodology of shape generation and shape optimization, this chapter first introduces the objective and means for the application of this designing method, defines its utilization background, explains its components, presents main content of logical formulation, controlling program writing and procedure execution, and then analyze its operating mechanism, thus figuring out technological routes for parametric design based on ecological shaping and creating conditions for its application.

3.1 Range and strategy for its application

With a purpose of exploring a feasible designing method based on parametric technologies and architectural ecological performance simulation in the context of a new era, the present study adheres to the principles of rationality, validity, convenience, consecution and openness. In this regard, it puts forward the application range and goal for the designing method after theoretical analysis and practical confirmation.

According to IEAANNEX 30 carried out by the International Energy Organization during 1995 to 1998, the complete life cycle of buildings is divided into seven links: scheme design, preliminary design, detailed design, equipment bidding, construction and debugging, operational management and architectural reforming. Among these, scheme design, preliminary design and detailed design are three phases subordinating to the designing part. The scheme designing phase plays a vital role in the performance of the design and 57% of the energy conservation measures have been settled during the scheme designing phase. As to ecological shaping buildings driven by ecological factors, the scheme application plays a more important role. In the meanwhile, fuzzy input of designing data established in the present study perfectly responds to the uncertainty and fuzziness of data parameters during the preliminary scheming process, thus providing solutions according to different data accuracy. In addition, owing to data interaction between the geometric molding platform and the environmental analysis platform in the present design, real-time data import, analysis and feedback of scheme data are realized, which is applicable to the intensive design modification in the scheming phase.

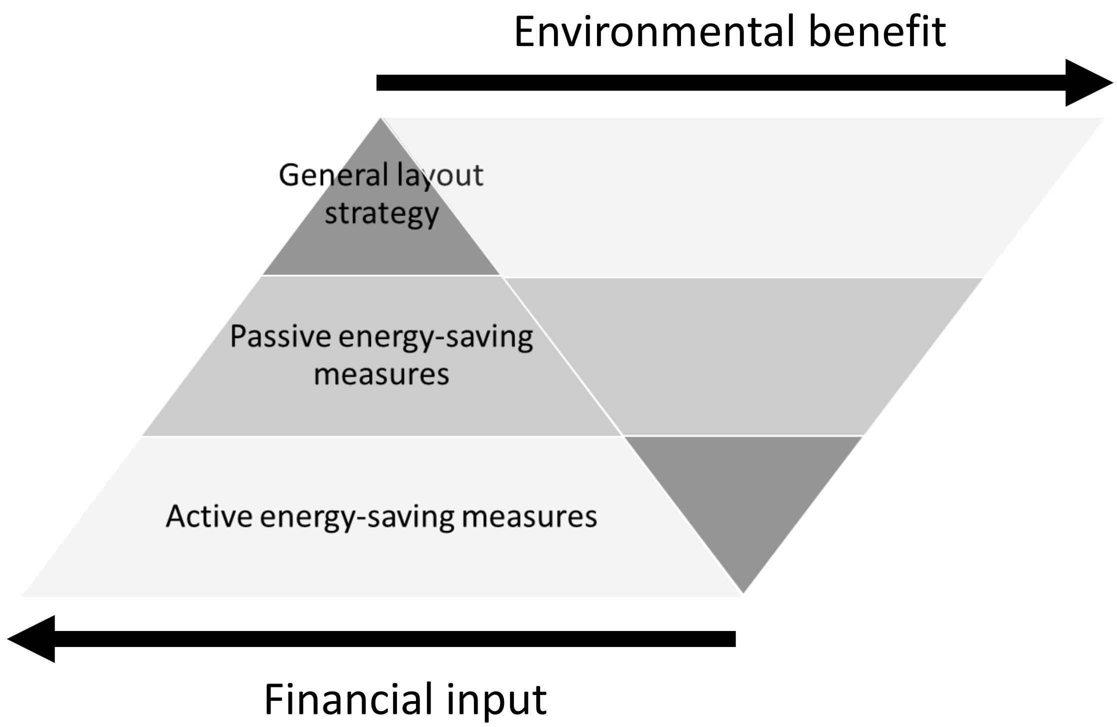


Chart 3-2 interaction between shape generation and shape optimization

Based on the above analysis, in the present research, we set the application of the designing method in the preliminary stage of the scheme designing.

3.2 Analysis of architectural shape generation procedures

3.2.1 Connotation of shape generation procedures

Shape generation procedure refers to the process of substantial restraints translating to virtual parametric logic and mathematical languages. In such a process, programmed instructions are used to define the relation and interactions among various elements and results are worked out in a way of charts and data. It covers set computation and data nodes. The former is the assembling of computing orders and time dimensional information, and the latter is the information group of space dimension. The set determines the sequence and logic of nodes while nodes play a role of storing computing results and transmitting data information in the set.

The input end is facing complex information set in the preliminary phase of designing, so restraints on input data type should be eliminated as much as possible. In the meanwhile, distinctive deciphers should be set up according to data types inside the generation procedures. Deciphers will translate the data into clear program languages for participating in the operation of generation logic. At the same time, the output data should be standard, structural and accurate so that they are able to be transferred in parallel optimization procedures. As the backbone for the entire design flow, shape generation procedure determines the development orientation of designing and the presentation forms of the ultimate result.

3.2.2 Composition of shape generation procedures

Shape generation procedure mainly comprises generation logic formulation, controlling program writing, procedure guided formation (execution), in a linearly organized manner. Designers analyze surroundings in accordance with requirements, put forward a preliminary concept accordingly, transform it to the generation logic of architectural forms, and realize its procedure functions on the parametric programming platform before computers implement computation and work out the

3.2.2.1 Formulation of generation logic

It bears great significance as the first step of the entire generation procedures, and targets to be achieved in this step include:

(1) Translating the original information: translating it into computer languages which can be accessed by downstream processes.

(2) Responding to the environment: inputting data such as site conditions, base environment and climate into Ecotect platform for simulative analysis and then the preliminary data model, based on which we can formulate response strategies according to design requirements.

It is notable that environmental features, climate and design requirements should be taken into account in a holistic way while formulating environment-response strategies. For example, in respect of sunlight conditions, buildings should face somewhere avoiding direct sunlight to eliminate air conditioning energy consumption in hot areas. While in cold areas, buildings are designed to face a direction that gets as much sunlight as possible to cut down heating supply demands. In hot areas, the sunward side should be covered appropriately to avoid heat radiation, while in cold areas, covering should be removed to acquire sufficient sunlight radiation. In terms of the wind environment, buildings in hot areas should be designed to stand in a position following the wind for the purpose of aeration and heat exchange. However, buildings in cold areas should be designed to stand in a position avoiding cold wind in winter. There is a long list of such examples and sometimes it is hard to coordinate due to excessive input conditions. In this regard, designers should follow his/her own designing principles to clarify the priority orders and direct the whole design flow with one or several response logic. Then, designers should carry out dynamic coordination to the whole system and make it a dynamic system with compensatory mechanism.

（1） Determining block functional organization: block functional organization is a process of setting size and location of building blocks according to design concept, block functional relations and environment response strategies. Block is a response to architectural forms and functional organization models, and also an environment-driven part. In such a process, designers should get a clear picture of the preliminary X, Y, Z anchor point and sizes of X, Y, Z axis. The scale of functional blocks is on the task manual. However, location relations such as layering, crossing or junction should be analyzed and judged by designers.

Determining geometric controlling elements. As the last step for generating logic definition, it means that special size, proportion and geometric controlling elements bear the task of transforming and storing the mentioned information. Both descriptive designing concept and logical response strategies need to establish data association with parametric programming and modeling platform through geometric controlling elements.

During shape generation, designers should analyze and clarify how architectural forms are influenced by dominant environmental factors. Besides, they should also determine methods to be applied combined with data analysis models and requirements for results in the design flow. Under the premise of realizing expected goals, data processing capacity could be compressed and logic elements forming data association could be optimized in order that the least computational cost could realize the most controlling while ensuring logical variety.

In conclusion, the establishment of shape generation logic is a process featured by the crossing and collaboration of subjective and objective elements. In face of complex condition input, such as the compound response of generation logic to diversified environmental influencing factors, designers should determine the value and priority of these factors based his/her own judgment. According to quantized data and past experience, they should take into account the association of environmental influencing factors and architectural shape geometric controlling factors in both quantitative and qualitative manner by virtue of his/her logical minds and designing experience.

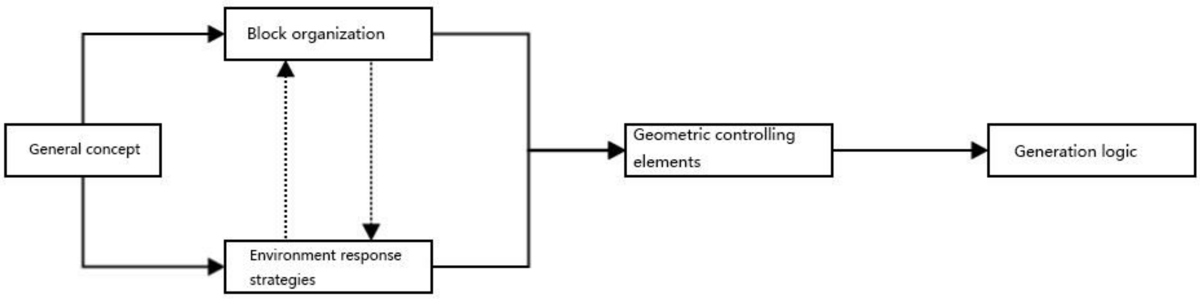


Chart 3-2 formulation process of shape generation logic

3.2.2.2 Shape generation controlling programming

Shape generation controlling programming is designed to transform the above mentioned shape generation logic into computer programming languages that can be recognized by three-dimensional modeling platform via parametric programming platform. Irrespective of the fact that the architectural shape generation process has been completely described and defined in the last phase and that the space and time relationship among all computing sets and data nodes has been clarified, its descriptive linguistic definition could not be recognized by computers while the whole designing has to analyze and process complex data that could be done by designers themselves via computer programs. In this regard, designers should translate and edit the definition of shape generation logic via parametric programming techniques afterwards.

In the present research, shape generation controlling program refers to the Grasshopper arithmetic device set to be motivated by shape generation programs to complete the task in a specific phase. A complete shape generation system comprises multiple interacting shape generation controllers, each of which bearing a specific shape generation task. Different sets try to realize control shape generation on complex forms via data connection and collaboration. Each shape generation controlling program is a complete system integrating parameter obtaining, algorithm generation and data connection, which enables it to carry out computing tasks independently. Among them, the algorithm generation part is a backbone for each shape generation controlling program or even the whole shape generation system since it stores the data of each computing operation to be transferred or edited by the next operation. In the meanwhile, it bears the computing task from data input to result output. In addition, data access in the parameter obtaining end is divided into constant data and variable data. Generally, constant data includes the following fixed parameters of the entire system, namely base location, size of the site, sunlight intensity, or content in the data reservoir of the shape generation system. In the whole design flow, the two are actually mutually transformable. For example, the block location relation of buildings is a variable to be determined in the discussion concerning architectural shape in the early scheming period. However, when it comes to the shape optimization period, it is considered as a constant in the data reservoir and used as the prototype for shape optimization.

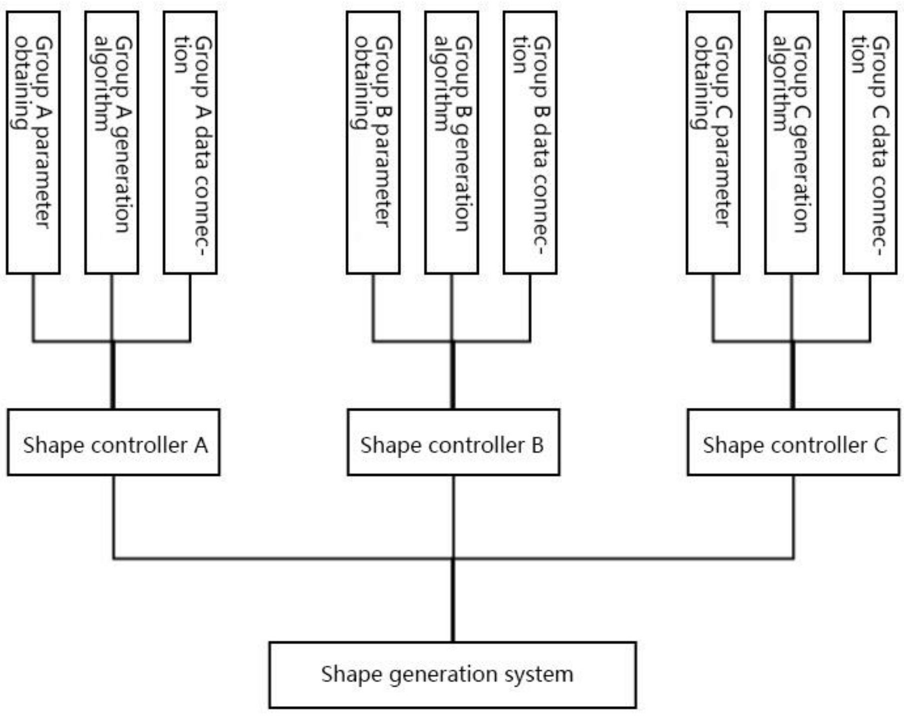


Chart 3-3 structure of shape generation controlling system

In respect of objectives, shape generation controlling program is classified into algorithm generation program, geometric controlling program and information exchange program, corresponding to various computing devices in Grasshopper. For example, algorithm generation program mainly transfers Math and Analysis and Util computing set of other geometric tabs, information exchange program tends to apply computing devices in Params and Sets, while geometric controlling program favors basic computing devices in its geometric tabs.

Algorithm generation programs work to determine specific working modes of each shape controller. They act as the brain of shape controllers since their output data is directly used to be stored and processed in the shape optimization system. In the present research, over ten subcategories are included, such as eyesight openness calculator, wind area calculator, volume change ratio calculator, surface coverage ratio calculator, influenced area calculator, surface openness calculator.

Geometric controlling program functions to generate and adjust geometric forms according to defined parameters and data. It is a bridge connecting information data and geometric forms in the program information pipe. In the present research, it covers seven subcategories, namely architectural block generation program, eyesight openness controlling program, wind environment influencing program, influenced area controlling program, sunlight radiation controlling program, surface generation program, and particle movement simulation program. Though realized computing categories vary, the data source can be summarized into three modes. For one thing, a part of controlling programs may generate geometric forms by directly inheriting preliminary parameters from designers, which is frequently used in the generation of initial building blocks. For another, some controlling programs have access to upstream output data, so they are able to generate geometric parameters of architectural forms and become a part of the existing computing chain.

Information exchange program functions to carry out interface negotiation and data transmission among three-dimensional modeling platform, parametric programming platform, performance simulative evaluation platform, and genetic algorithm optimizing searching platform. It is responsible for the leading-in of architectural geometric information into architectural performance simulation platform, the leading-in of architectural performance simulation data into parametric programming platform as well as the storage and access to architectural performance simulation data. In the present research, it is sub-divided into wind environment simulation interactive program and sunlight radiation simulation interactive program. Information exchange program provides reliable technical support for data connection between performance simulation platform and three-dimension modeling platform and parametric programming platform, which makes it a technological basis for the realization of simulative data directly acting on the architectural shape generation.

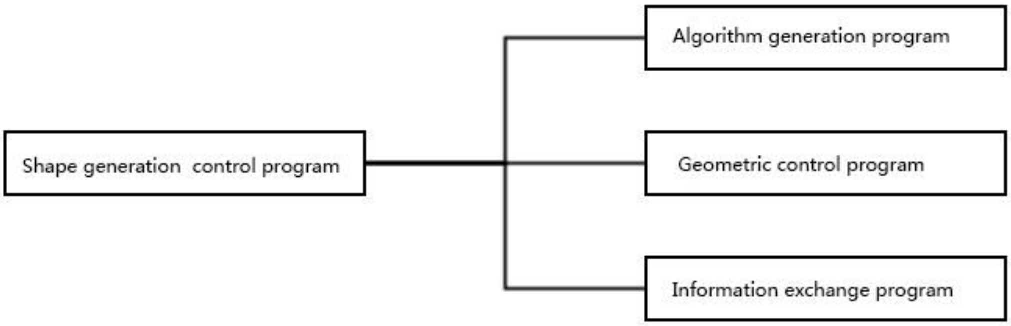


Chart 3-4 classification of shape generation control program

While programming, designers need to invoke commands relating to generation logic to constitute the algorithm generation program assembling. By matching the algorithm assembling, geometric topological information can be delivered in the architectural generation process.

Then, based on the dimensional relations of algorithm assembling in generation logic, data connection can be realized in each command. It is notable that we should choose appropriate data connection mode according to distinctive data interface and downstream calculator types.

At last, it is required to insert required parameters (basically environment and climate data, architectural function data and site microclimate simulation data in the present study) in the input end of shape generation control system and insert downstream optimization program data interface in the output end, thus preparing for the successive shape optimization procedures.

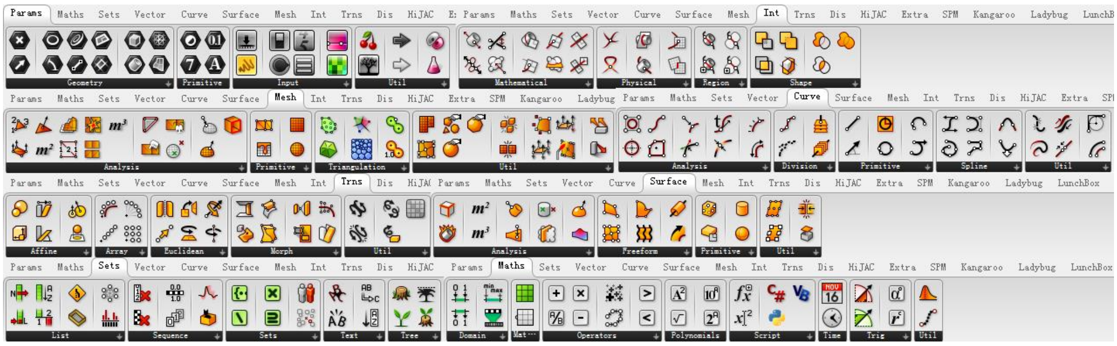


Chart 3-5 Grasshopper calculator

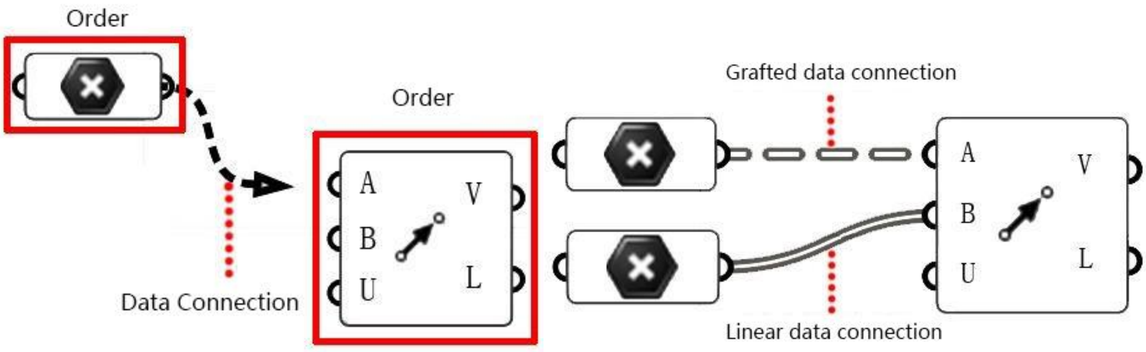


Chart 3-6 sketch of Grasshopper data connection[64]

3.2.2.3 Execution of shape generation program

The execution of shape generation program, the final step in the entire system, is the embodiment of generation logic. In respect of the general shape generation system, the execution part plays a central role in the data transmission of the system. For one thing, parametric information and mathematic logic in the generation program are derived in the phase, whose result may be used directly and further edited from parametric programming platform to three-dimensional modeling platform. For another, the data may be transferred into the shape optimization platform, thus developing from the shape self-organizational generation phase to the operation in the genetic algorithm optimization phase. Specifically, it incorporates tree sub-procedures of architectural block generation, architectural refined curve generation and architectural surface generation.

Architectural block generation is the first procedure. Block is a embryo shape containing architectural functions in the first phase of shape generation program execution. According to design requirements and concepts, designers determine the organizational mode and geometric relations among blocks. In general case, architectural forms may be dissected into several sub-blocks for convenience of calculation and analysis. These sub-blocks, as the abstract expression of architectural forms, are finally reshaped and organized into authentic architectural blocks after topological transformation. Blocks are generally divided according to function requirements. While designing, designers should adjust geometric relations according to streamline organization, wind field influence and sunlight sheltering.

Architectural refinement curve generation follows when data drive of performance-

[64]. Han Yunsong. Research on Architectural ShapeShape generationShape generation Methodology Based on Sunlight and Win Environment Influences: [D]. Harbin: Thesis for Master Degree of Harbin Institute of Technology, 2012:36.

based analysis software is introduced in the shape generation process. It covers three operation steps, namely architectural shape refinement and remolding under the influence of wind environment, performance-driven curve optimization and architectural section shape optimization. Designers first import architectural blocks generated in the previous phase into the environment performance simulation platform for analysis, then acquire the base CFD simulation data implanted in the blocks and finally import them to the parametric molding platform. By virtue of the generation control program, they are able to transform CFD simulation data into corresponding geometric control elements before they work out the 3D wind field-based architectural section geometric control curve with the particle movement simulation program, thus getting the preliminary shape of generated buildings. After finishing this, designers will carry out performance-driven shape optimization and also remedy the relevant complete architectural shape combined with functional and structural requirements.

In the last phase for shape generation, designers will further modify and adjust generated forms combined with sunlight, eyesight and other elements, carry out real-time linkage with shape optimization platform, adjust their design by virtue of the joint action of parametric optimization and human-computer interaction, and finally work out the result.

3.3 Analysis on architectural shape optimization program

Architectural shape optimization program parallels architectural shape generation program, and it studies the generated result of the latter. It is an evaluation system that analyzes the results with a series of pre-established optimization factors and filtering standards, reports the analyzing results and advices to shape generation program afterwards for its modification and optimization. In such a program, architectural ecological performance simulation software and parametric design platform are combined to realize dynamic data connection between the two by virtue of data interaction, thus achieving environment ecological elements-based architectural shape optimization.

Its components, programming procedures and execution are just similar to the corresponding parts in the architectural shape generation program. Likewise, it is also based on Grasshopper parametric programming platform. In this regard, similarities between the two will not be repeated here, and the following will focus on the distinctive parts and the interactive working mode between the two.

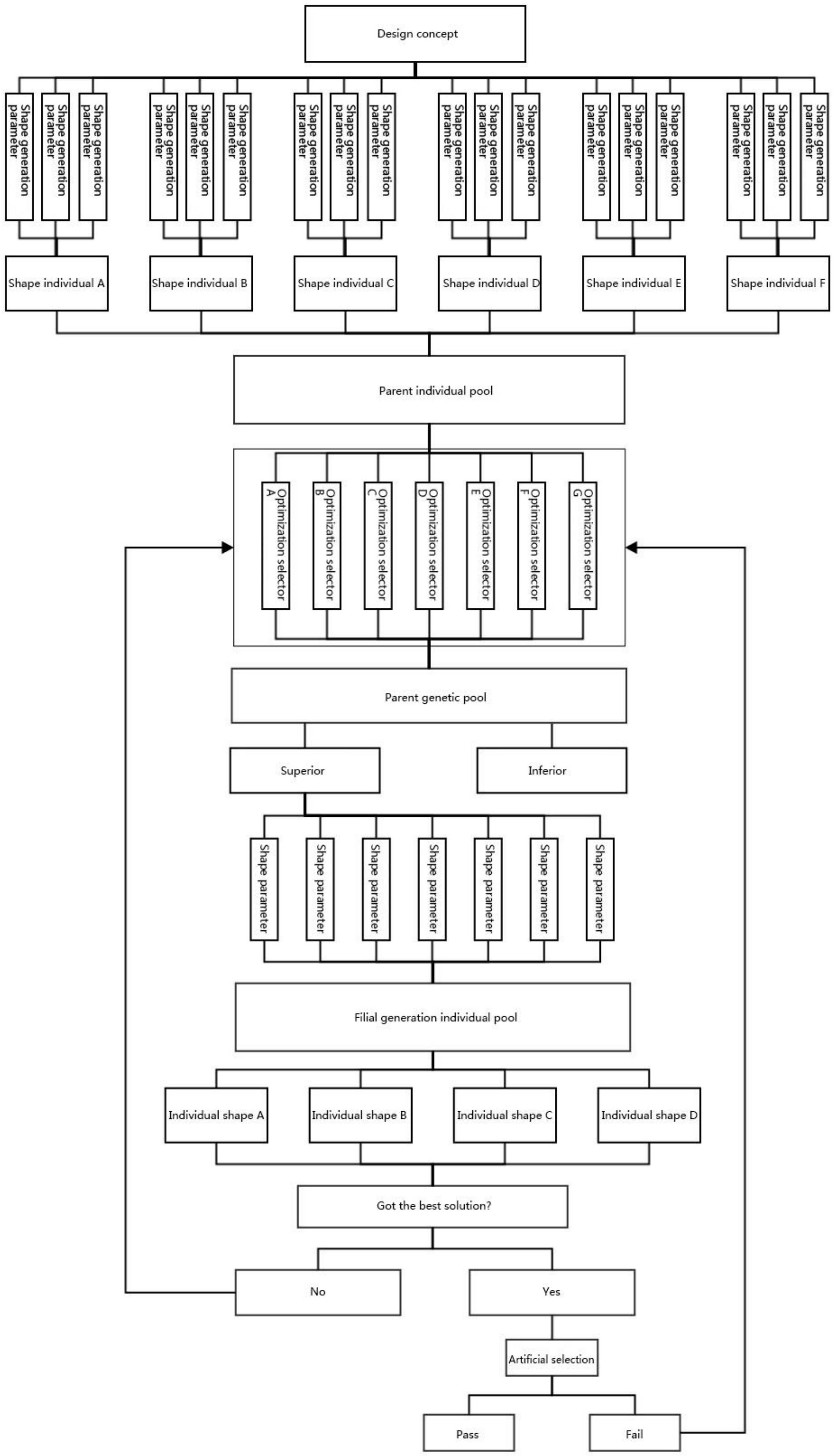


Chart 3-7 Framework of the shape optimization program system

3.3.1 Definition of shape optimization program

Shape optimization program is a definition assembling of parametric logic and mathematic languages that deal with and analyze data worked out in the architectural shape generation phase. Different from the shape generation program, it includes data set dissection, analysis, searching, selection, re-arrangement, optimization selection calculators by virtue of specific algorithm. In the present research, Galapagos genetic algorithm optimization searcher is taken as the core calculator.

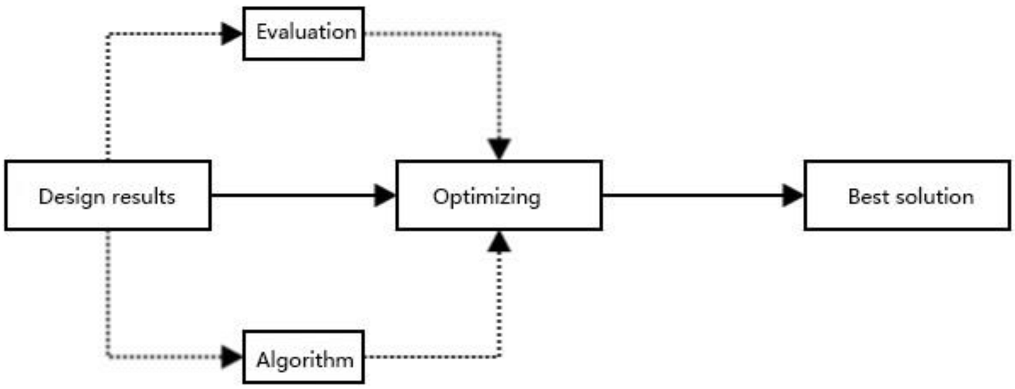
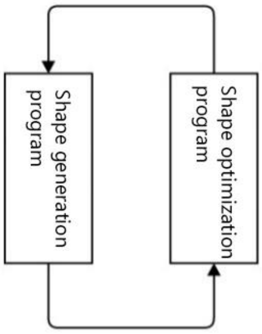


Chart 3-8 formulating procedure for shape optimization logic

3.2.2 Composition of shape optimization program

Shape optimization program also comprises logic formulation, control programming and program execution. In this regard, it is similar to the shape generation program system. However, the two are not equivalent. They are different in three ways. For one thing, they have opposite data transmission path. Data to be analyzed and upgraded by the optimization program derives from the result of the shape generation program and the adjusted elements act on data input of the generation program in return. Secondly, they differ in thought patterns. Optimization program is to upgrade, search and select designed variables according to pre-established goal and calculating path in a top-down way. Instead, the shape generation program is a down-top self-organizing generation process of randomly designed variables according to shape generation logic. Thirdly, they function in different ways. After optimization selection of input data, shape optimization program only exports evaluation results and parameter modification suggestions, rather than exerts direct influence on geometric data on parametric programming platform or 3D modeling platform. They only present after the application and feedback from the shape generation program. On the contrary, shape generation program is able to present geometric data directly and realize its operation by Bake. It is justifiable to say that shape optimization program is the sufficient but not necessary condition for shape generation program.



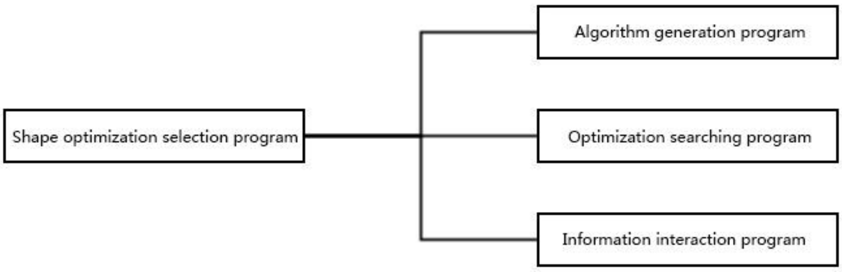


Chart 3-9 Dialectical relation between optimization system and generation system (left), Classification of shape optimization control program (right)

In the meanwhile, in respect of program classification, since optimization selection program generates evaluation factors instead of acting on geometric shape directly, geometric control program is not involved as in shape generation program. Instead, its optimization searching program is applied here to realize the function of optimization searching and evaluation.

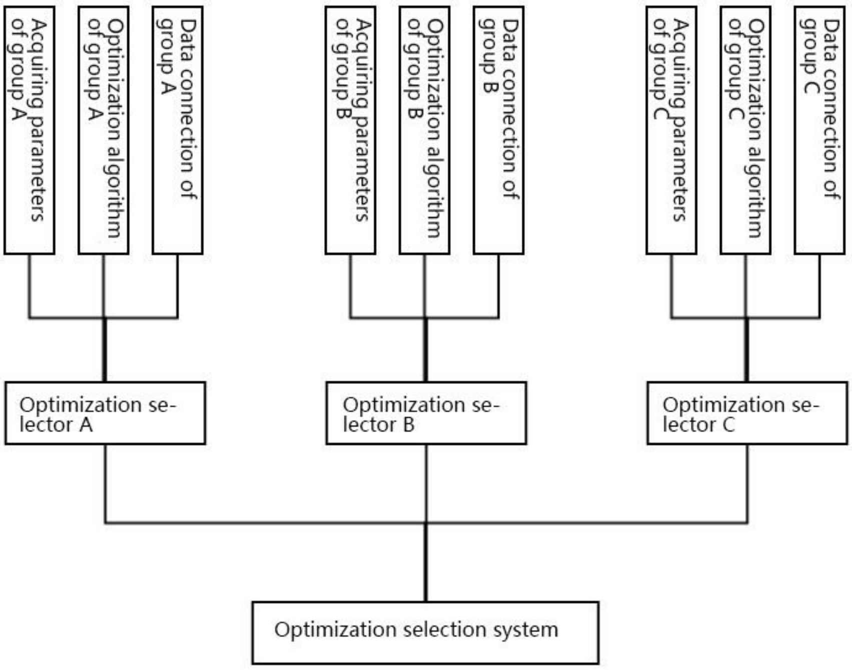


Chart 3-10 structure of shape optimization control system

Chapter IV Application of Parametric Architectural Design Based on Ecological Shaping

This chapter mainly explores the application of parametric design based on ecological shaping in architectural areas. It expounds the application of this methodology in different phases when it goes through the development from vague to clear designing concept and from general design goals to concrete schemes. Based on various features of each design phase, it presents how to formulate generation and optimization logic according to different conditions in an orderly and well-planned way. In addition, it also reveals how to realize its application in architectural block generation, shape optimization and detailed designing with the combination of artificial selection and modification.

4.1 Introduction to basic designing information

4.1.1 Plot environment

Chart 4-1 Porto Antico in the history[65]

The project is located in Porto Antico, Genova, Italy. Since 5th century B.C., the port has been an important military base of North Roman Empire. The earliest man-made construction in the port was dock for landing troopships. The development of Genova made it a key commercial center in the Mediterranean Sea. In 16th century, the economic growth in Genova reached its peak, which made it one of the busiest ports in the world. From the 20th century, the port gradually switched its shipment function to the new port in western part of the city. As a result, this area had to witness its economic collapse, and the circumstance proceeded to 1992 when the re-establishment in this area began.

The remodeling, led by the Italian architect Renzo Piano, was carried out with the purpose of rebuilding infrastructures in this area, integrating it into urban life and renovating the most attractive tourist spot in the city. Commercial, business, entertainment and public functions were achieved under such a principle, and it has become la Piazza sul Mediterraneo[66] in its real sense.

Chart 4-2 Panorama of Genova Porto Antico[67]

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65. Genova egy 1482-ben készült festményen
66. http://www.portoantico.it/
67. http://www.portoantico.it

Chart 4-3 Location of the program plot[68]

The present design is located in the southern part of the port. Once being a freight terminal, it is now abandoned, covering an area of 9600 square meters. The designed is expected to revive the port and make it a tourist attraction in the southern part of the city and the gateway of the port.

4.1.2 Design requirements

The design principle requires taking account of the geological conditions and cultural histories of the city the program locates in, choosing appropriate architectural forms for improving regional vitality. It also regulates a building area of 40000 square meters and appropriate functional distribution.

[68]. Google Earth

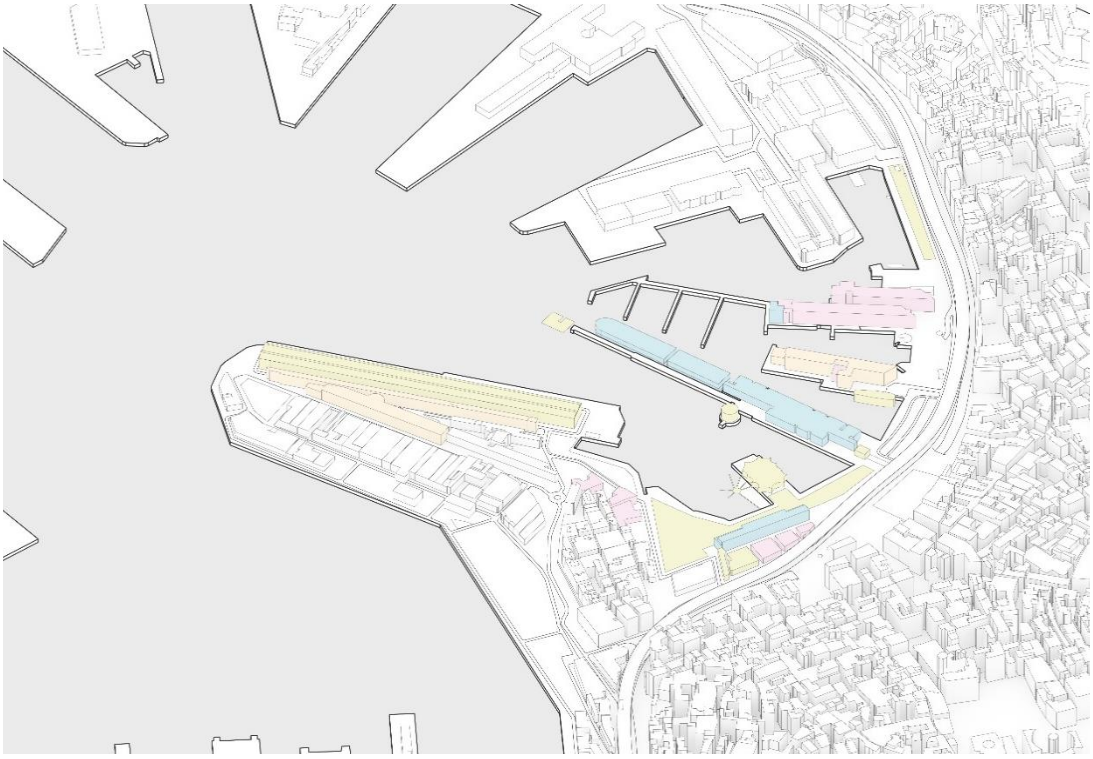


Chart 4-4 functional distribution of major buildings in the area

The chart below shows the functional distribution analysis on existing buildings in the area. The green part represents leisure and entertainment function, red part represents catering business function, blue part represents public exhibition and the orange part represents office function.

4.2 Refinement of design concepts

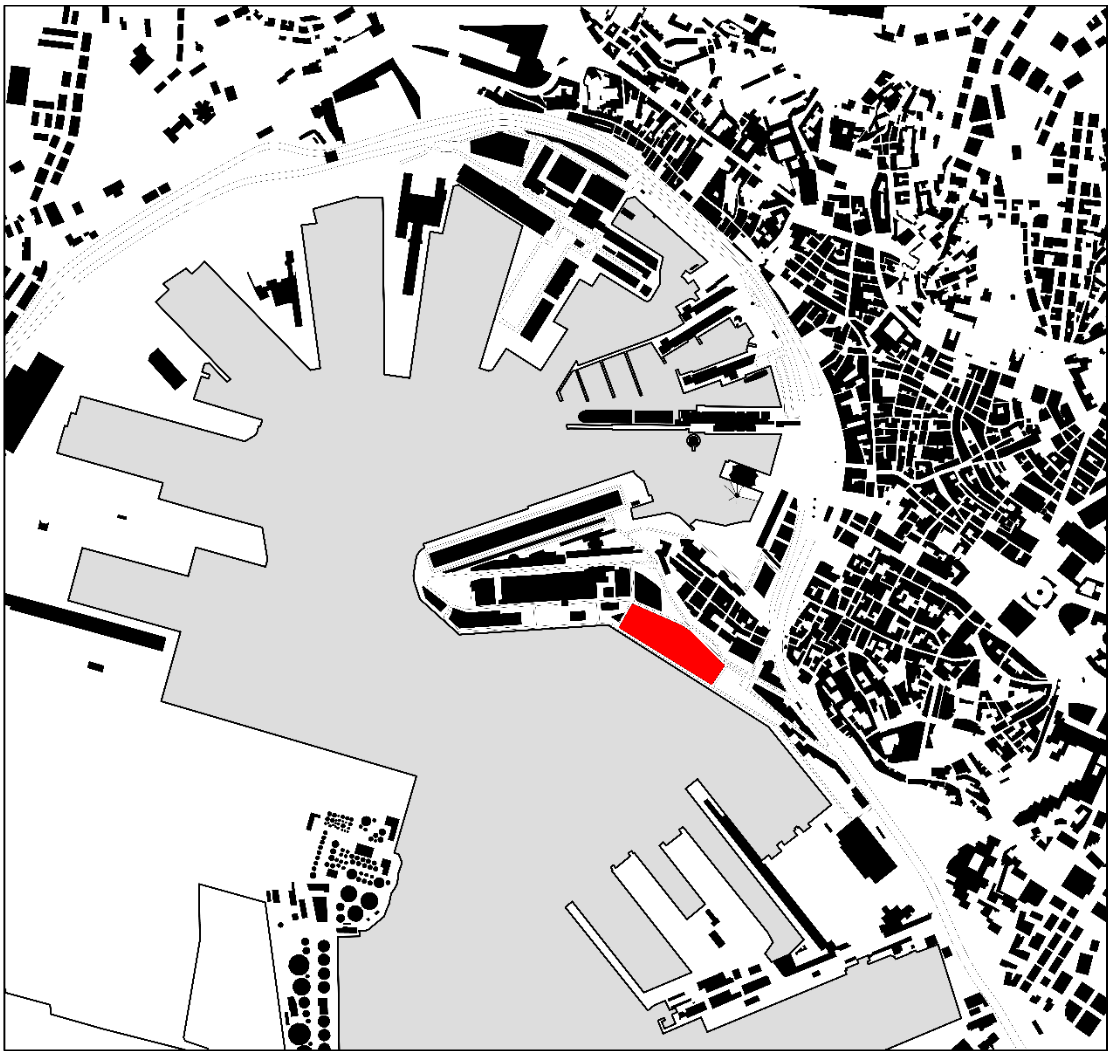
4.2.1 Concept generation

The program base, located in the south end of the port area, far from the central region, with limited visiting population and passive urban space, is almost abandoned. Generally, urban activities happen in open area of the north part of the city. In the meanwhile, we notice that the program base is adjacent to the southeastern exit of the region while connecting to traffic arteries across the entire Genoa urban areas. At the same time, it adjoins the coast line. With favorable geological conditions, it has great potential for renovation.

Based on the above analysis, we set the primary goals of the concept development phase as follows: motivating and remolding surroundings by virtue of the present design so as to expand vitality boundary of the old port and extent urban network; introducing existing activities and urban causes in the eastern part of the region into the base; and exhibiting city images on key attractions such as port and overhead roads.

We carried out investigation on functions of major buildings near the base and reached the following conclusions: existing buildings in the area are generally in cluster, and each area bears its won functional theme. For example, the function of the triangle square in the northeastern part of the base in mainly catering service, island in the northern part of the base is featured by buildings with exhibition functions, mainly aquarium, and buildings in the northern part are mainly for catering and office business. The advantage of such a organizational mode lies in its distinctive theme of regional activities, which facilitates distinctive services for people with various purposes. However, the disadvantage is that exchanges among groups are not encouraged, which will result in potential division to the entire region. It will hinder population decentralization and resource integration, thus exerting passive influence on the improvement of regional vitality.

Chart 4-5 Base for the design program



We then studied regional activity flows and organizational patterns and found out that due to the special zigzag geological features and its clustering function organizing patterns, flows of the existing activities are generally linear, and spaces with various functions are tied in this "function line", which leads to tortuous functional flows and thus impedes the association and remolding of the entire activity space.

Based on the above analysis, we decide to input a linear multi-functional complex

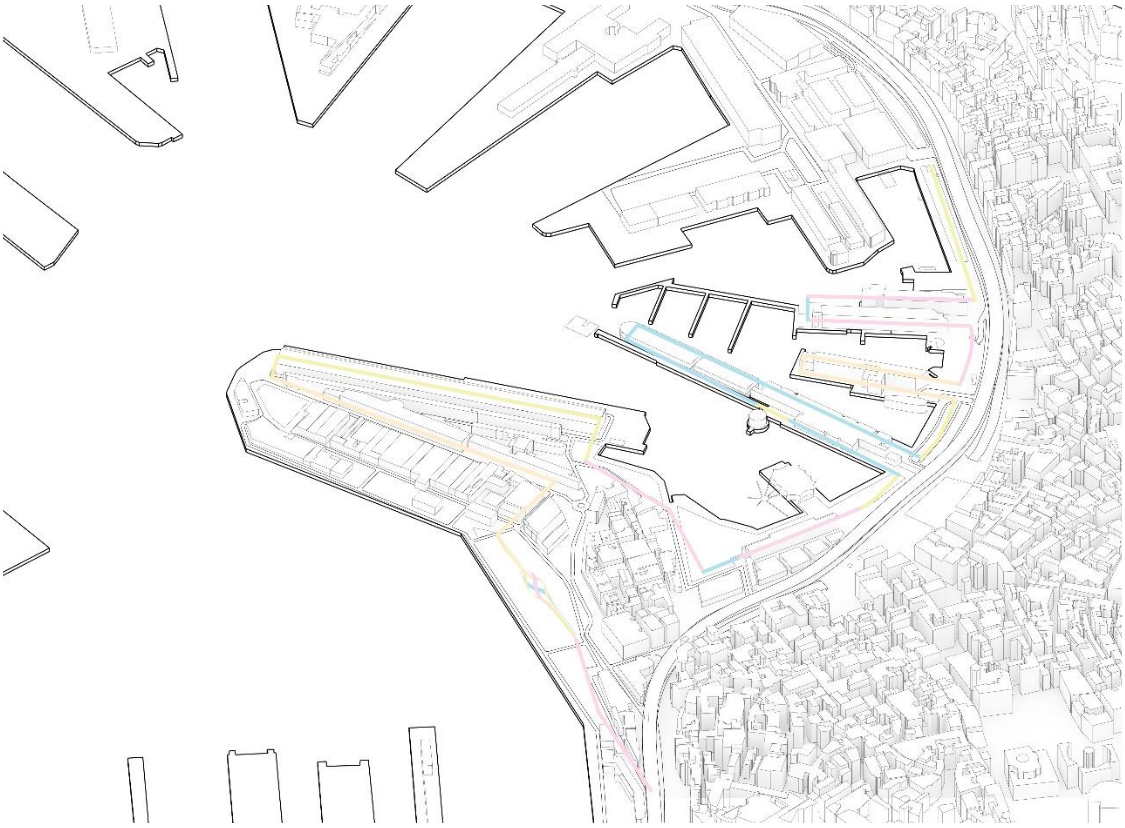


Chart 4-6 People’s activity paths in the base

in the design, which is able to ease but not interrupt the linear space. In the meanwhile, we elevate the weight of the southern part in the entire special sequence so as to realize the expected design objectives. We arrive at the following concept by deepening the above conclusion.

To begin with, in respect of shape organization, we allocate various functions along the major axis of the base in a linear pattern, so as to continue the general spatial logic in the region. In the meanwhile, we reverse the shape, so that spaces with various functions mix, concatenate and communicate, thus making it possible for the generation of heterogeneous spaces. It weaves all functions and forms a powerful force field with architectural spaces, thus elevating vitality in the region.

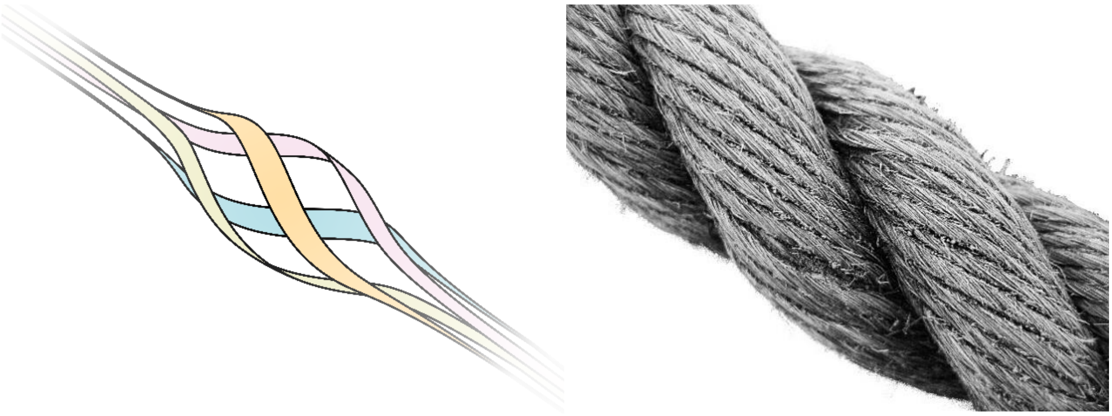


Chart 4-7 Design concept: weaving spaces and force fields

Moreover, in respect of functional arrangement, we decide to incorporate four functions of commerce, exhibition, entertainment and business with a comprehensive consideration of regional demands in a distribution proportion of surrounding buildings. The specific area proportion is as follows:

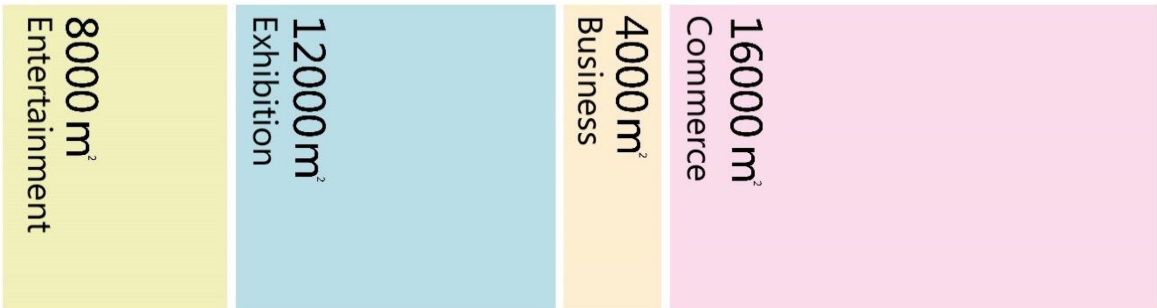


Chart 4-8 demands for designed functional areas

4.2.2 Analysis on base environment

The plot is located in North Italia with Mediterranean climate which is featured by hotness and dryness in summer, warmth and wetness in winter as well as affluent precipitation. The best sun exposure direction is a 25° angle between east south and the long axis of the base. Sun exposure is intensive in summer, which makes it necessary to take into account of the shadowing of surroundings and heat-resistance performance of buildings.

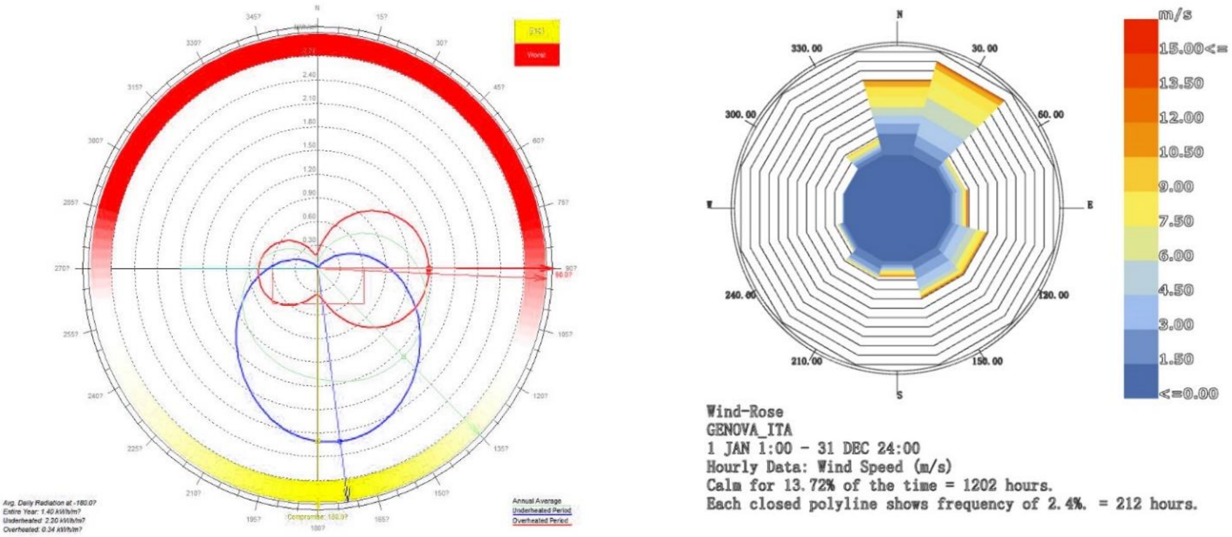


Chart 4-9 Best orientation and wind rose map of building in the base according to Ecotect analysis

In the meanwhile, the base is adjacent to sea in its south and the predominant wind direction is north-east. The site has to stand in speedy wind without any shelters. It should be thoroughly considered in the design so that buildings could face less wind load. At the same time, by optimizing allocation of buildings, wind environment of the buildings will be improved a lot.

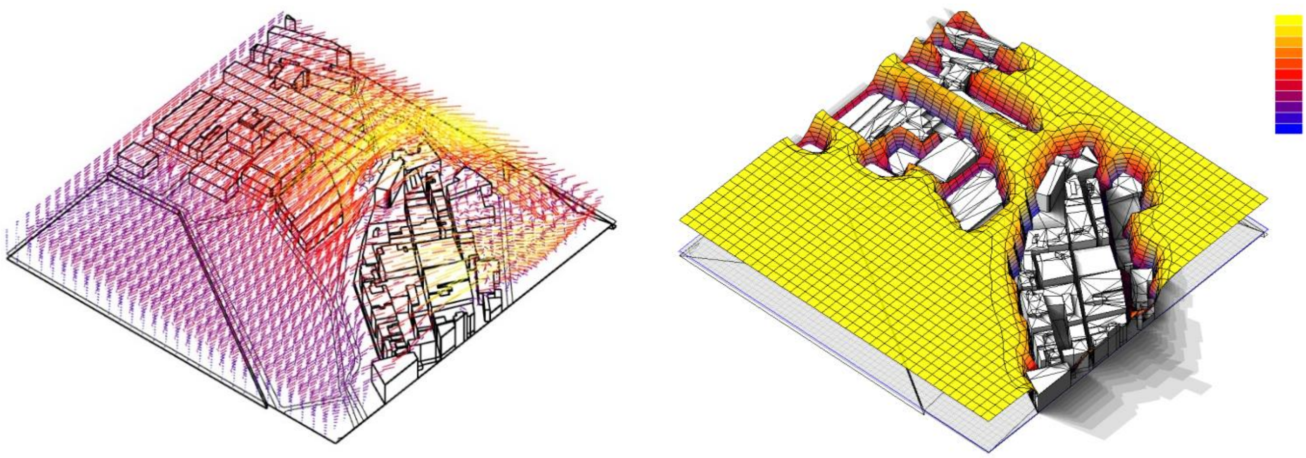


Chart 4-10 analysis result of the wind environment of Winair base

Last but not least, in consideration of the expected landmark role of the building, key eyesight nodes around the base should be seeable. In addition, since the base resides in the peripheral coastline of the port with favorable landscapes, it should get response in respect of block organization patterns and architectural volumes.

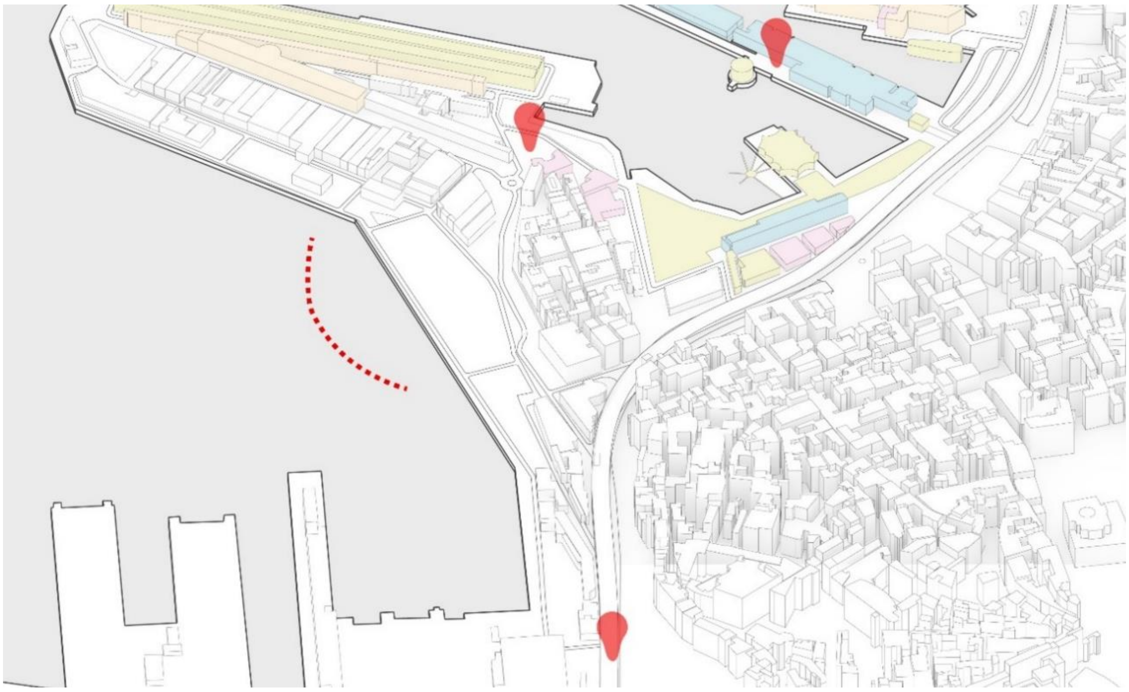


Chart 4-11 analysis on seeable landscapes in the base

To sum up, we formulate the following environmental response strategies:

(1) Buildings should face a direction that is perpendicular to the direction of the most sun exposure in order to reduce sunlight radiation as much as possible. Buildings should try to find shelter for themselves in respect of forms, thus reducing sunlight radiation of the exposed facet. While trying the window style, sunlight should be taken into full account. Facets with the most sunlight exposure should open the windows as less as possible. Instead, window areas of facets with less sunlight exposure could be increased. In the meanwhile, open areas of the building should be equipped with favorable sun blocking facilities.

(2) In respect of architectural shape, predominant wind direction in summer should be taken into consideration in order to facilitate ventilation. In the meanwhile, architectural forms should comply with the wind field of the base, so that streamlining facets that facilitate the reduction of wind load and benefit the environment should be applied.

(3) Architectural distribution and height control should take into account of the visibility of key landscape nodes as well as the clearness of eyesight.

	Sunlight environment	Wind environment	Eyesight
Facing direction of the building	Perpendicular to the best sunlight direction	Facing predominant wind direction	—
Volume organization	Blocking sun for surrounding open areas	Improving surrounding wind environment	Ensuring visibility of key nodes
Architectural shape	Improving blocking for themselves	Setting streamlining facet	Conforming to the definition of landmark buildings
Windows on facet	Less opened window with more sunlight exposure	—	Opening window more with high demands on eyesight clearness.

Chart 4-12 Environmental response strategies of buildings

4.3 Block generation

Block generation refers to a process of writing shape generation programs with parametric programming platform based on the previously developed design concept. In addition, optimization selection platform will be motivated to carry out evaluation according to the above designed environmental response strategies. The process is conducted for the purpose of generating basic architectural blocks in the preliminary scheming stage and prepare for further design in the next step. It is noticeable that the generation and evaluation logic for each phase are included in the response strategies. Redefined mathematic logic according to specific requirements and design variables are deemed to be concretized logic framework mentioned previously.

4.3.1 Shape generation

With the completion of design concept and site analysis, we defined the following shape generation logic in this phase:

(1) Allocation of architectural functional blocks along long axis of the base.

(2) Independent allocation of different functional blocks according to prescribed areas of the design task and their functional requirements.

(3) At least one crossing point between two functional blocks so as to shape spaces for communication and openness.

(4) Spaces should be spared for the main entrance in the western, eastern and southern facets of the base while designing block allocation. In the meanwhile, at least one alley should be left out below the architectural volume for connecting the three spots, thus forming a space for urban activities in the future while also ensuring the visibility of landscapes.

Generation control program is written on the basis of such logic. Generation control program is divided into four sub-programs, namely block control line generator, courtyard influencing factor generator, block generator and block storage. The four programs proceed in a linear sequence.

(1) Block control generator: since blocks are allocated along the long axis of the base, we connect two randomly chosen spots and take the eastern and western facets as the reference surfaces to generate the preliminary block control line.

(2) Courtyard influencing factor generator: connecting the outlet end of the above mentioned control line to the courtyard influencing factor generator. This calculator, operating on the basis of physical laws, entwines control lines by virtue of interacting power fields. In the meanwhile, it realizes disturbance to block allocation by imposing repulsive forces on control lines and randomly generated courtyards and alleys.

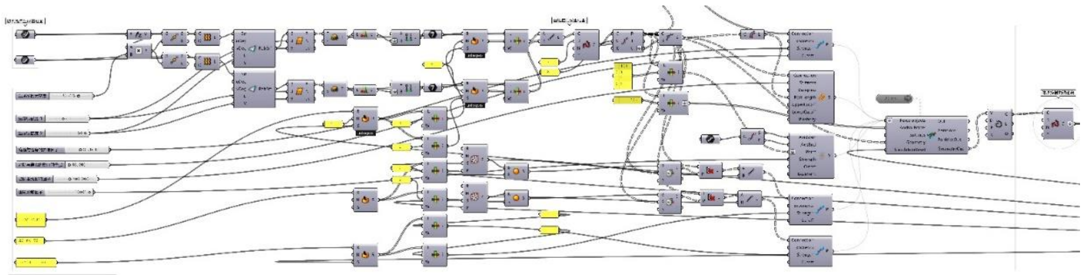


Chart 4-13 Block control line generator

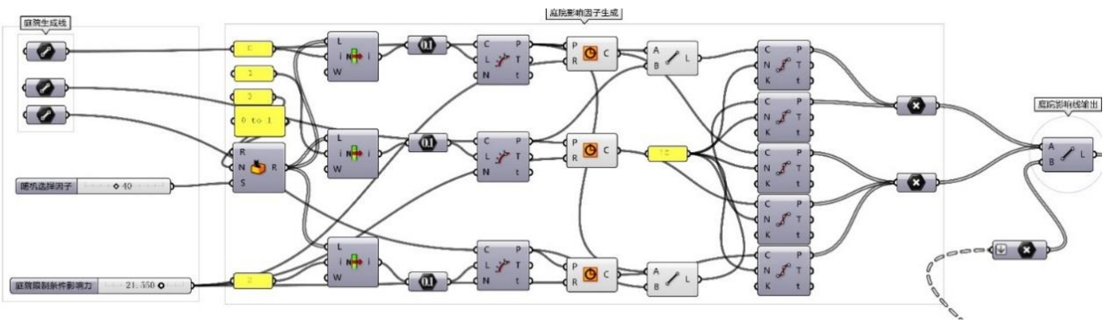


Chart 4-14 Courtyard influencing factor generator

(3) Block generator: we introduce the control curves generated in the previous procedures into the shape generator. According to the pre-set requirements for

functional areas and floor heights, the program will choose specific curves in accordance with certain principles and generate architectural blocks responding to requirements of the design task. It is noteworthy that selection of reference control curves with various functions is carried out with pre-set orientation rules. For example, ground floor commercial interface bears more commercial functions compared to limited exhibition functions. As a result, control curves close to the ground are more likely chosen by commercial functions for block generation. Likewise, curves on top level are more likely chosen by exhibition functions.

(4) Block memorizer: after generating architectural blocks based on control curves, shape assembling emerged from multiple random parameters will be stored in memorizer for result optimization in the next step, so that data transfer may be realized in the shape optimization program. It should be stressed that memorizer should with concertedly with Hoopsnake calculator which enables data chain circle to realize automatic generation and storage of multiple forms generated by various parameters.

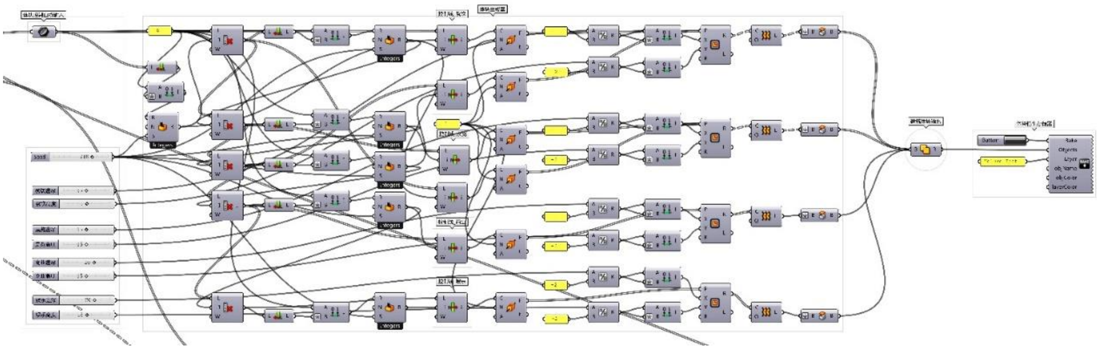


Chart 4-15 Block generator

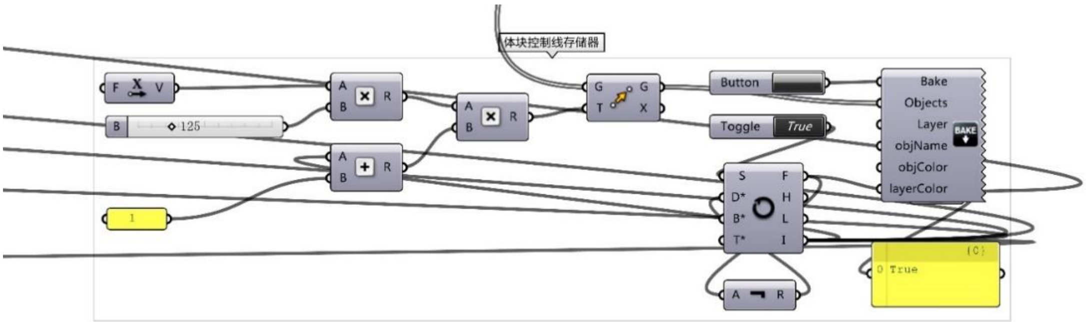


Chart -16 Block memorizer

The block generation process ends here. The core of the process lies in the emergence of various results as much as possible under the influence of designed generation logic and influencing factors according to random preliminary parameters, thus providing possibilities for furthering design schemes. In this regard, traditional design methodology is unable to achieve that due to the limits of brain calculation capacity and its creation mechanism (created things are actually the re-extraction of stored experience in brain) [69].

Here we generated a total of 100 distinctive results waiting for further filtering.

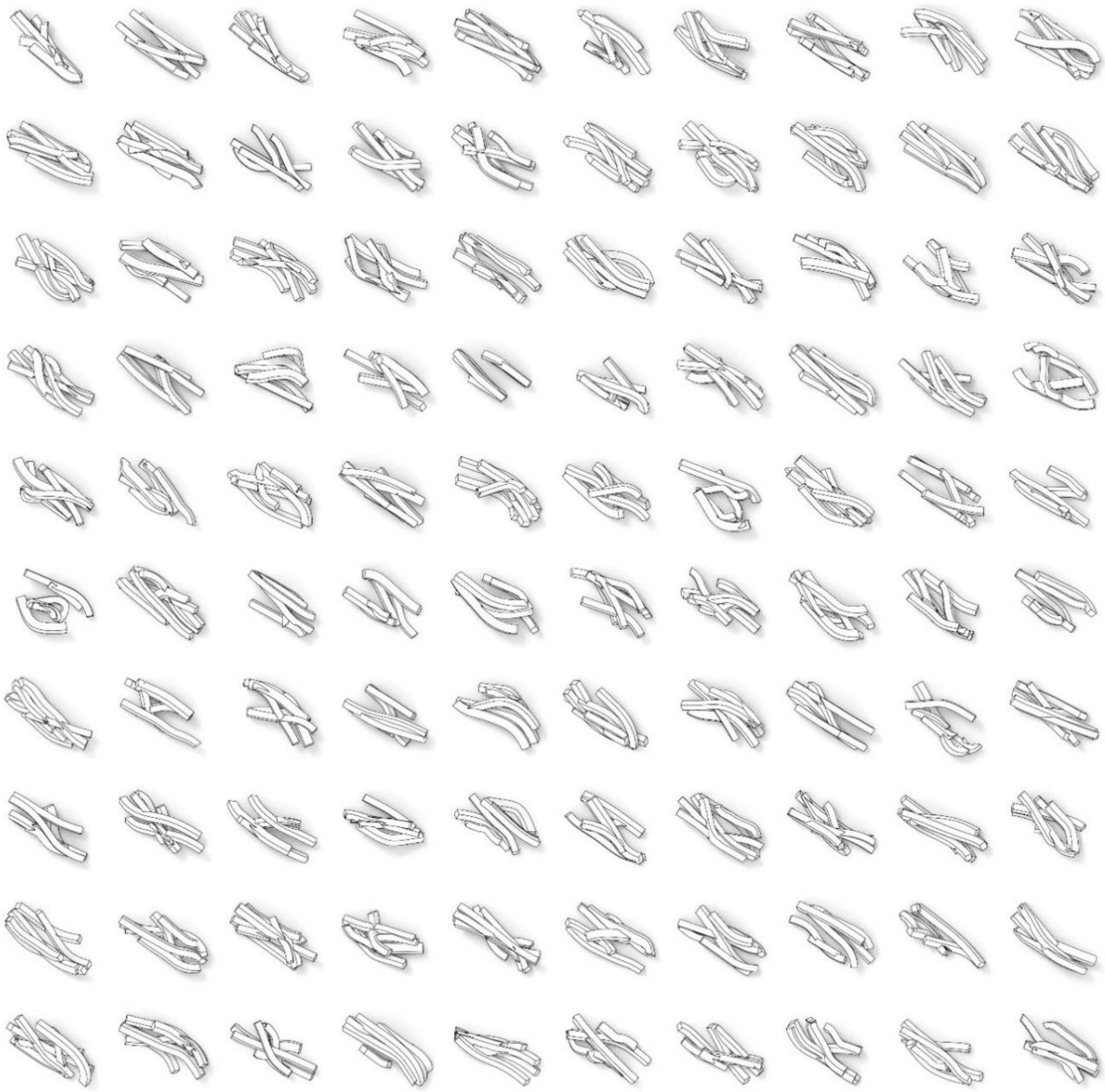


Chart 4-18 100 emerged shape possibilities

4.3.2 Shape evaluation

Objectives of this step are as follows: working out optimization selection algorithm and evaluation mechanism based on the previously mentioned environmental response strategy. In respect of operations, evaluation standards are concretized as follows:

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[69]. Kostas Terzidis. Algorithmic Architecture. Architectural Press 2006: 32

(1) Evaluating the wind environment of architectural blocks with "average wind speed ratio" being the standard. According to the evaluation methodology, wind speed of the passengers' height surround the buildings constantly change with incoming flow. In this regard, it is of limited practical significance to acquire the wind speed value of each sample spots under a certain experimental wind speed with wind tunnel test or value simulation[70]. Accordingly, wind speed ratio R_w could be taken as the evaluation parameter in order to study amenity of wind environment surrounding buildings, which is able to reflect the change of wind speed caused by existing buildings. [71]

$$Ri=Ui/Ui'$$

In the equation, Ui is the wind speed of the passengers' height of location i in the wind field when buildings exist, and the unit is m/s;

Ui' is the wind speed of the passengers' height of the same location in the wind field when buildings do not exist, and the unit is m/s.

The following equation is derived according to the calculation methodology of average wind speed ration in "heat environment design standards for urban residential areas" [72].

$$R= -0.507\times\zeta+0.244\times\kappa+0.697$$

In the equation, R is the average wind speed ratio in the field, and κ is the first-layer aerial ratio of buildings in the field (%)

Z is the ventilation coefficient in the field, which is the product of architectural density and the front face area ratio ζ_s of its dominant wind direction.

$$\zeta_s=F_w/F_{wmax}$$

Front face area is the projected area of buildings on the dominant wind direction they face, which is approximately the size of the windshield facet of buildings. In the meanwhile, buildings will get the maxim projected area in a certain direction[73], which is called the maxim possible front face. The front face area ratio is a number between 0 and 1.

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70. 申杰. 基于 Grasshopper 的绿色建筑技术分析方法应用研究[D]. 广州:华南理工大学硕士学位论文. 2012:58~60
Shen Jie. Study on the Application of Grasshopper-based Green Architectural Technology Analysis [D]. Guangzhou: Dissertation for Master Degree of South China University of Technology. 2012:58~60

71. 李琼. 湿热地区组团规划设计对室外微气候的影响 [D]. 广州; 华南理工大学,2009
Li Qiong. Influence of Humid and Hot Area Planning on Outdoor Microclimate [D]. Guangzhou: South China University of Technology, 2009.

72. 城市居住区热环境设计标准(征求意见稿初稿) [M]. 2009
Heat Environment Design Standards for Urban Residential Areas (draft for suggestion soliciting)

73. 陈佳明. 基于集总参数法的居住区热环境计算程序开发 [D]. 广州; 华南理工大学,2010
Chen Jiaming. Lumped Parameter-based Heat Environment Calculating Program Development in Residential Areas [D]. Guangzhou: South China University of Technology, 2010.

In the equation, ζ_s is the front face area

F_w is the front face area of dominant wind direction of buildings (m^2)

F_{wmax} is the maxim possible front face area of buildings (m^2)

From the equation, we conclude that the smaller the front face area, the more favorable to the ventilation and the higher the evaluation. In addition, its values are closely associated with architectural forms. That why we chose it as the evaluation parameter for assessing wind environment performance of architectural forms.

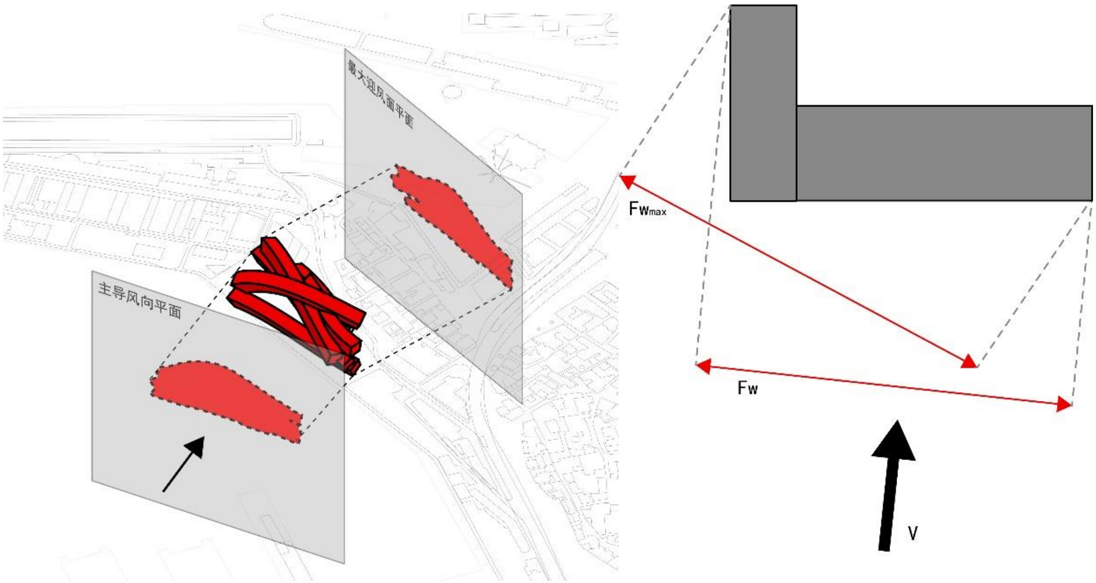


Chart 4-19 Shape evaluation standard 1: average wind speed ratio

(2) Visual accessibility of architectural volume in three key urban spatial spots is deemed to be the visibility evaluation factor. The three sample spots are respectively elevated road to the east of the building, activity square adjacent to the north of the building, and the aquarium long land to the north of the building. Light from these samples gets blocked by existing buildings in the environment, then arrives at where the building locates. The larger is the visible projecting area in the region, the higher the score.

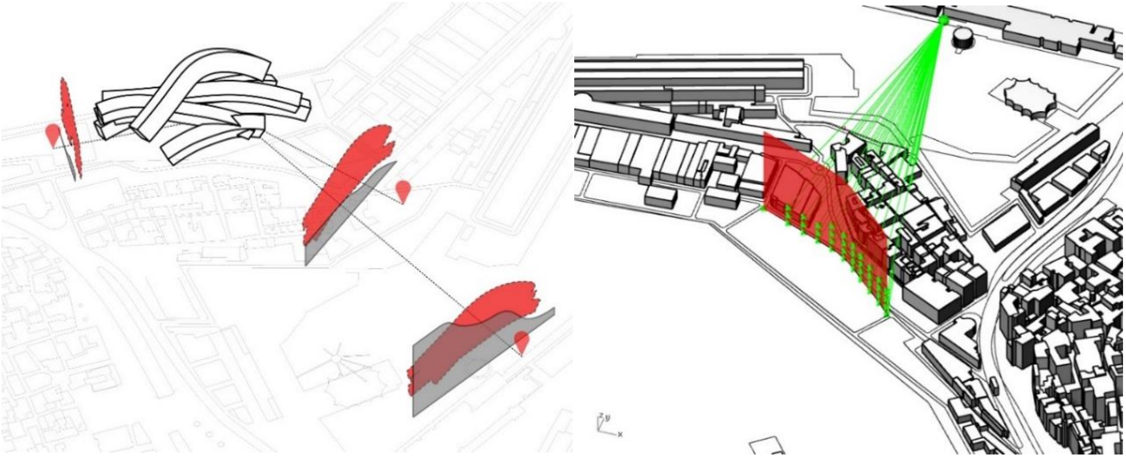


Chart 4-20 Shape evaluation standard 2: visual accessibility of key spots

Based on the above evaluation logic, we write the evaluation control program and carry out the evaluation process, which comprises block reader, visual blockage rate calculator, front face area ratio calculator and general evaluator. Among the four sub-programs, visual blockage ratio calculation and front face area ratio calculation are carried out simultaneously, and the other two are implemented in a linear sequence. At last, we evaluate the 100 architectural forms generated in the last phase and select the top ten blocks.

(1) Block reader: it is designed to filter data with corresponding number from the 100 architectural forms generated in the shape generation program, and input it into shape optimization evaluation program.

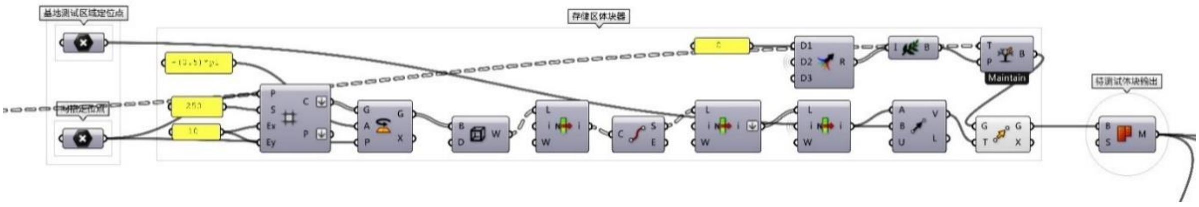


Chart 4-21 Shape evaluation control program 1: block reader

（2） Front face area ratio calculator: in practical operation, we work out the projecting base according to the longest axis direction of the building and the dominant wind direction of the region, and then project architectural blocks into the two facets respectively, and finally get the difference of the projecting areas.

（3） Visual blockage ratio calculator: the working principle of the calculator is to project straight line to buildings from each vision sample, and create a visual plane perpendicular to the line in this direction. Then we project the building and surrounding structures to the visual plane and get the projecting area difference, which is the visual blockage ratio.

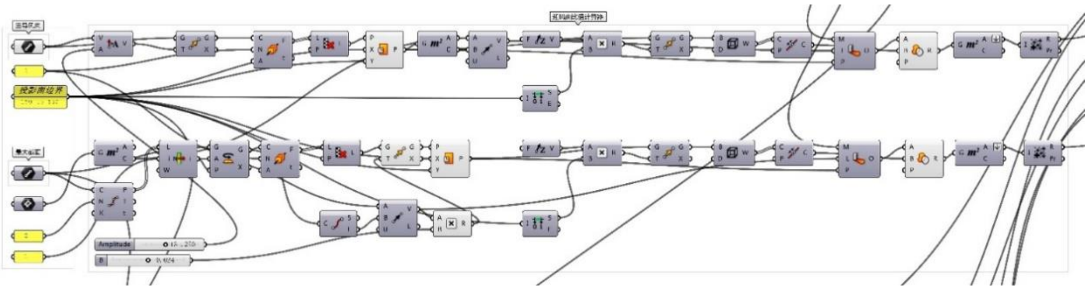


Chart 4-22 Shape evaluation control program 2: front face area ratio calculator

（4） General evaluator: it is a phase to work out the final grading of architectural forms in the pre-set evaluation standards, which includes data input, weight allocation, cycling switch and data storage. The weight allocation part is a tool applied by designers to adjust priority of evaluation factors according to practical circumstances and design requirements, thus facilitating the processing of complex evaluation factors. For example, during evaluation on the present shape, among the three vision samples, designers presume that the visional spot of elevated road is crucial since it is located in the urban center, and followed by aquarium long land. Since adjacent activity square is able to perceive activities inside the base through other means, it is the least important. As a result, the weight coefficients of the three evaluation factors are set to be 1, 0.8 and 0.6. in the meanwhile, in order to better compare the grading differences between each block, the final scores are added a 1000-times magnifier for the convenience of comparing the score difference.

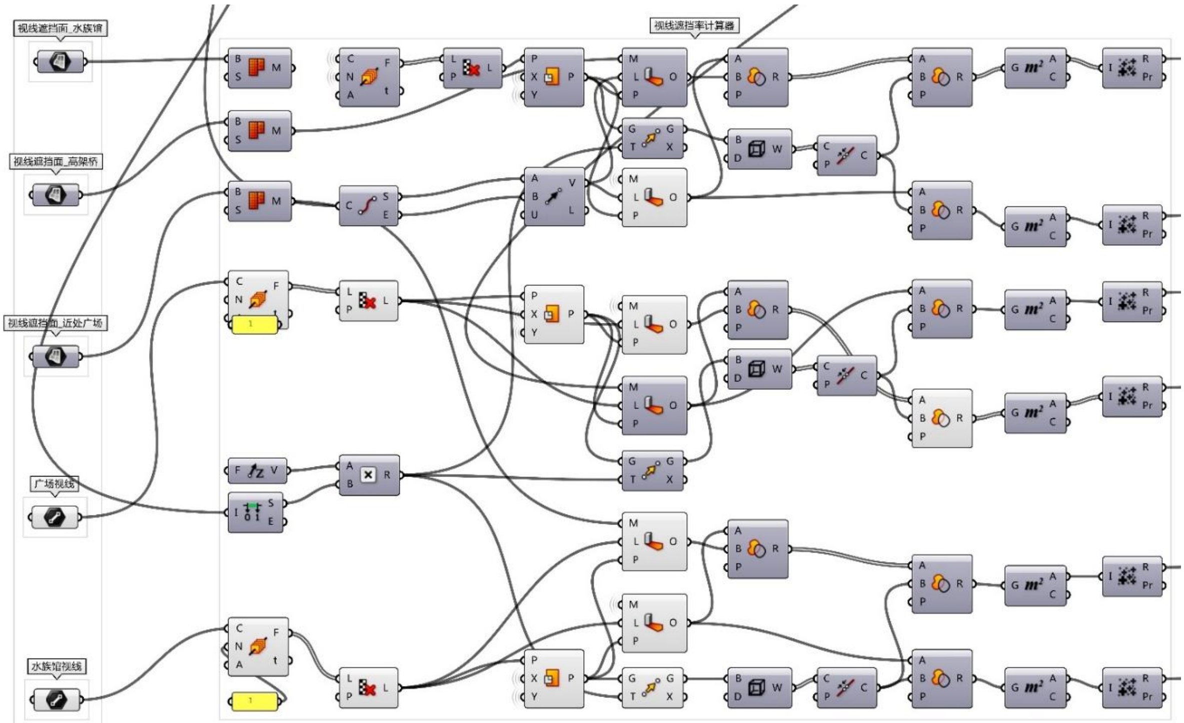


Chart 4-23 Shape evaluation control program 3: visual blockage ratio calculator

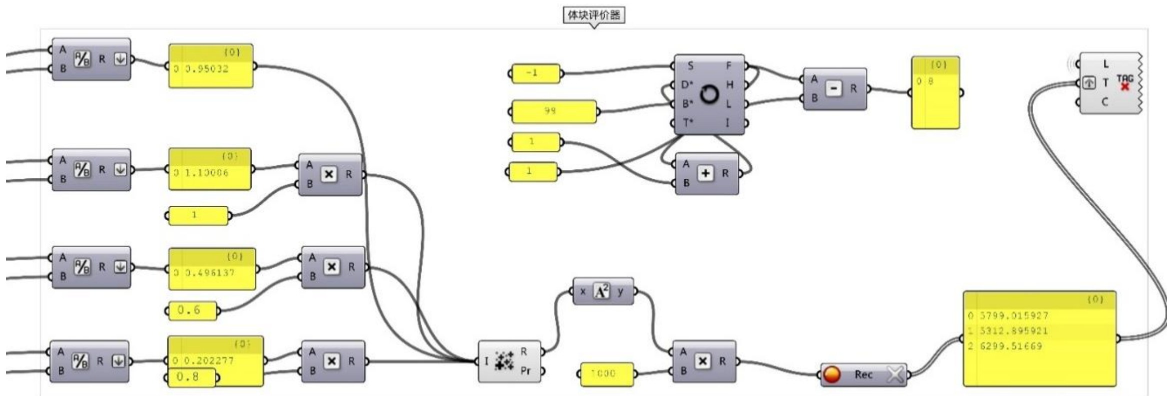


Chart 4-24 Shape evaluation control program 4: general evaluator

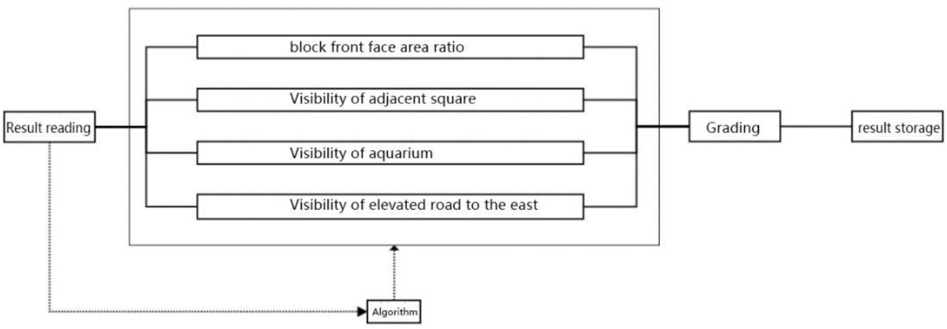


Chart 4-25 Logical framework of shape evaluation control program

By this step, we have worked out the scores for the 100 primary architectural blocks in the previous phase. After sorting the scores, we select our top ten.

Chart 4-26 Shape evaluation result: score sheets

Chart 4-27 Shape evaluation result: top ten

4.3.3 Artificial final selection

Based on the two procedures of down-top self-organizational shape generation and top-down environmental optimization evaluation, we ensure the variety of concept development in the early phase and also guarantee its rationality in functional and environmental sense. However, just like buildings being the perfect integration of techniques and arts, architectural design is the close combination of rational derivation and sensational creation. Integrated function of program system alone will not meet the demands of architectural design. Here, it is crucial for designer to intervene the filtering of selection results. It's worth mentioning that the process is the integration of designers' own thoughts, favors, spatial possibility, shape difficulty level and functional feasibility.

We choose the first group of blocks based on the rationality of spatial allocation and the richness of possible spaces generated from block allocation relations.

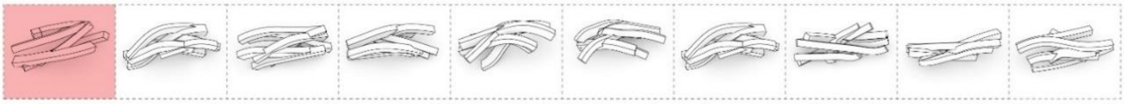


Chart 4-28 Shape evaluation result: artificial final selection result (marked in red)

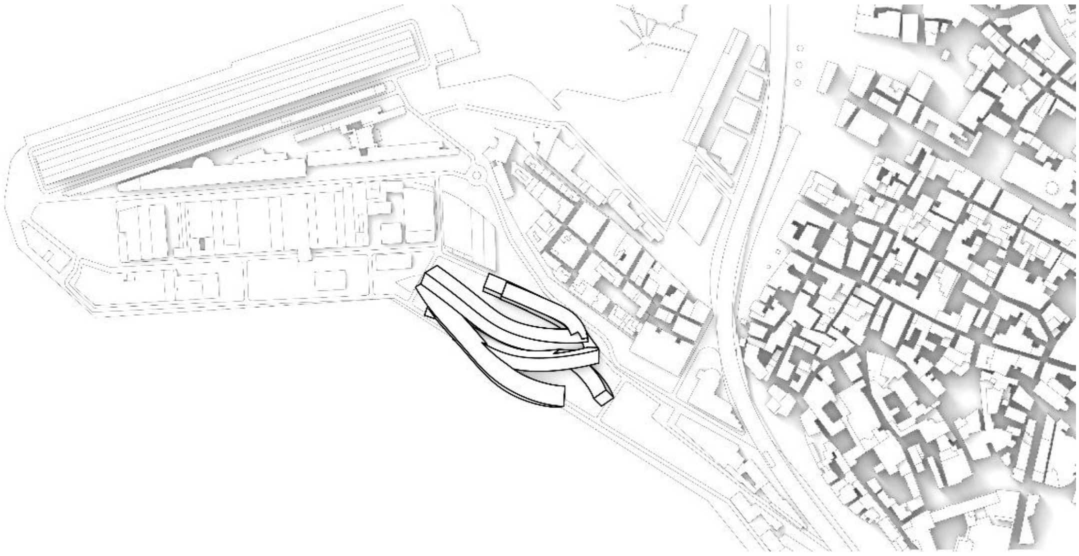


Chart 4-29 Final result of the block generation phase: general layout

From the general layout, we can see that the block is natural in shape, and functions are crossing in a reasonable way. Square in the lower part of the volume is used to contain urban activities. In respect of space, part of the block is hanging, which makes it permeable. Its shape is complex in general, which makes it flexible and possible to generate interesting urban spaces.

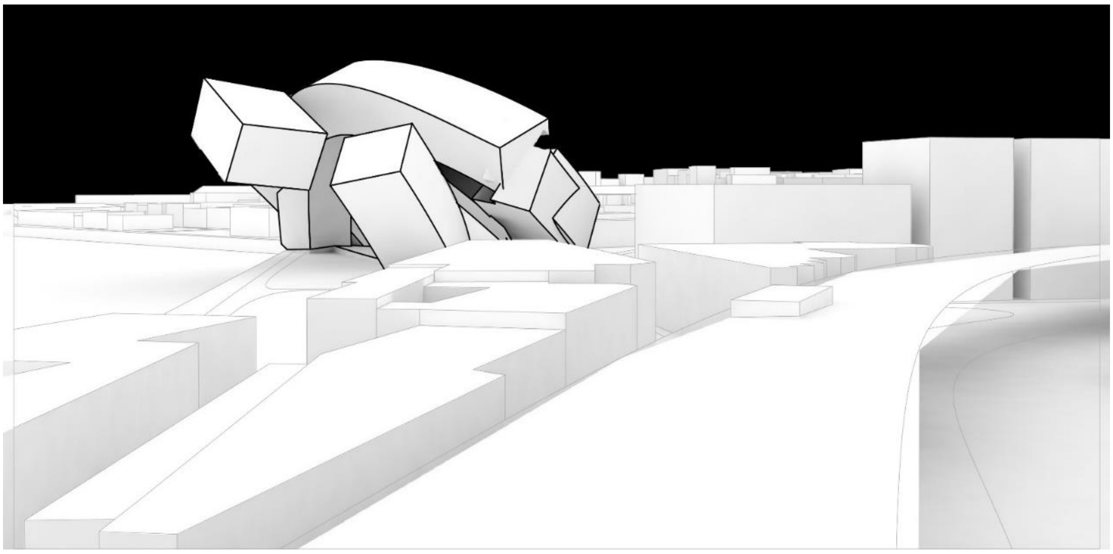


Chart 4-30 Final result of block generation phase: perspective from the elevated road

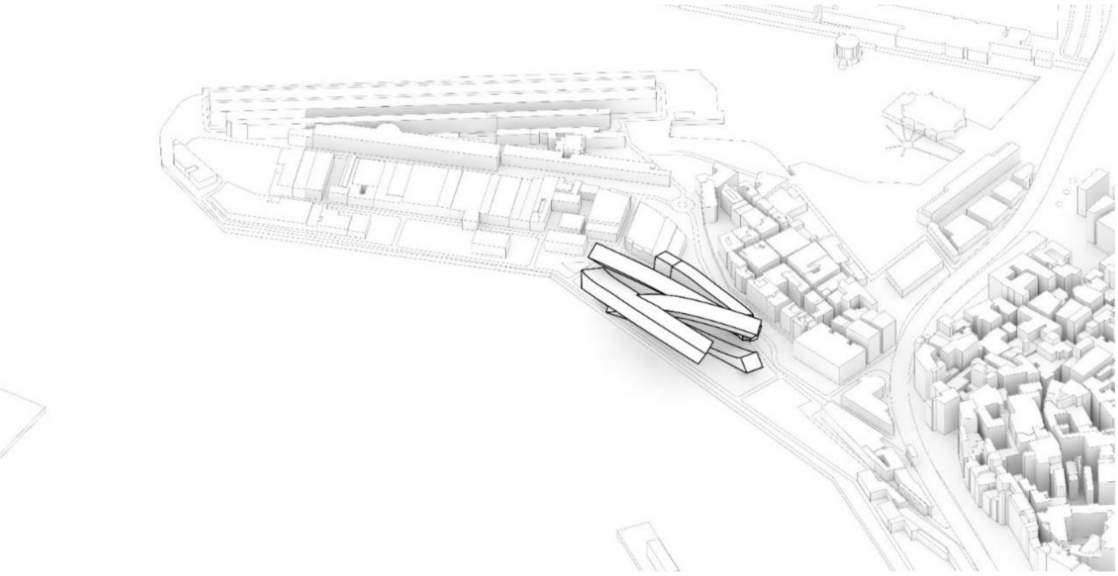


Chart 4-31 Final result of the block generation phase: axonometric measurement

Block generation and optimization selection in the primary stage of scheming end by now, and the final shape will be the base for the refining work of the next stage. 587 computing devices are motivated in the present process for the two phases of shape generation and shape evaluation. In addition, 8 programs are written to fulfill expected results.

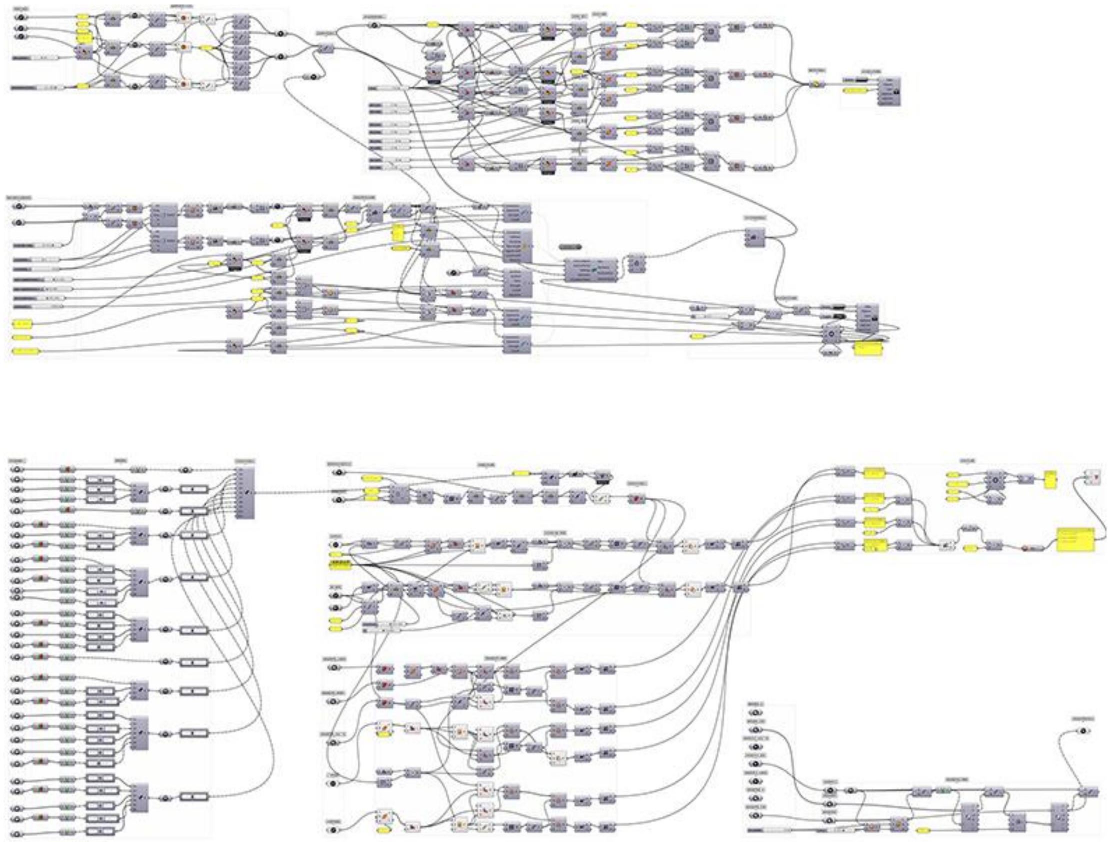


Chart 4-32 Program assembling in the block generation phase

4.4 Shape refinement

The design process is a development mode of regional circulation and overall progression. At the initial development phase of the program, the initial block of the program has been attained in the generation-evaluation process last step. At this phase, according to the environmental response strategy, within the category of shape optimization, further adjustment and optimization must be done on it.

4.4.1 Shape remodeling

In nature, this phase is still shape generation according to parametric logic. The reason why it is called "shape remodeling" is to distinguish it from the process of "shape generation" at the phase of block generation. The major difference between the two is that "shape remodeling" is "regeneration" of the shape according to more detailed and accurate environmental response logic and environmental control factors based on the results from the previous generative system operation of the block. Therefore, it is a progressive process, so it is called "shape remodeling".

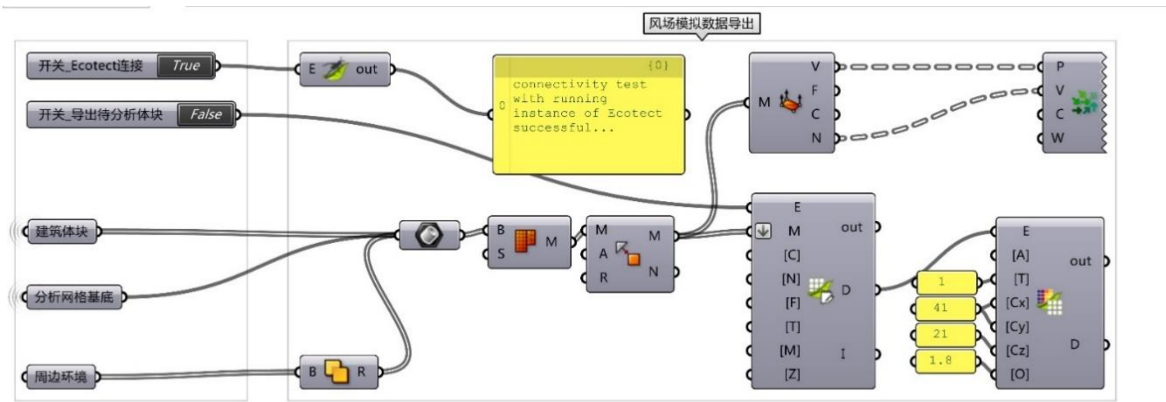
The operation logic of shape remodeling procedure is as follows:

(1) The initial block information obtained in the previous process is input into the site, and its wind environment is simulated so as to find out the actual wind environment condition of the base under its influence.

(2) Under the influence of wind environment, the geometry will be adjusted to minimize its wind load and optimize its wind guidance.

The control program of the generation process of shape remodeling procedure on the operational level is mainly composed of six parts: Ecotect data interaction program, sectional wind field picker, wind field particle simulator, control section generator, section control line generator and surface reconstructor. They are in a linear relation.

(1) Ecotect data interaction program: its function is to import the data of the architecture block into Ecotect, and the analyzed data will be exported to Grasshopper platform. In the data interactive process, attention must be paid to the corresponding relation between the analyzed data and the imported data, and an appropriate data path should be selected. Through this step, we can get the wind environment of the base under the influence of the building block. Because of the complex calculation of wind environment and its overmuch occupation of resources, in order to guarantee the smooth calculation process as well as a better influence on block adjustment, here it is simplified into 10 wind field sections in the directional of its long axis of the vertical architecture for simulation and analysis.



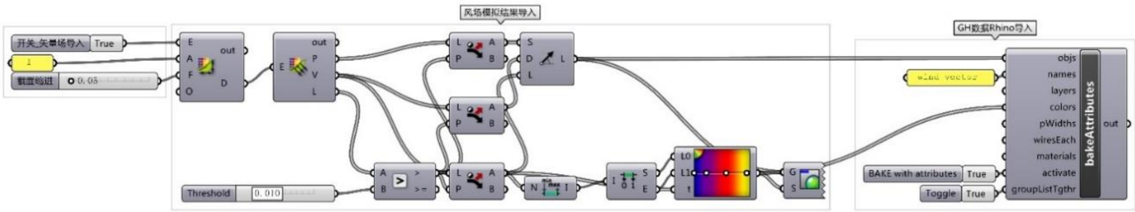


Chart 4-33 Shape remodeling procedure 1:Ecotect data interaction program

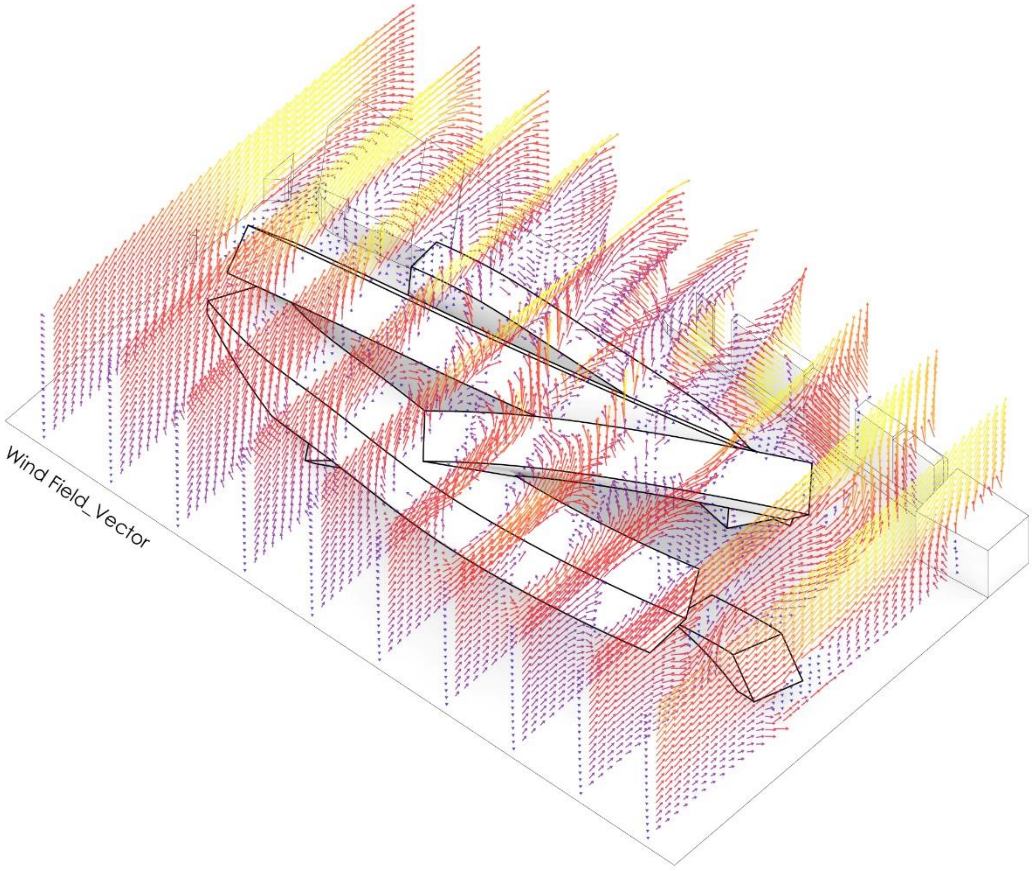


Chart 4-34 Sectional wind field vector quantity

(2) Sectional wind field picker: its function is to pick up the wind field data obtained in the previous step so as to be prepared for the simulation of wind filed particle in next step.

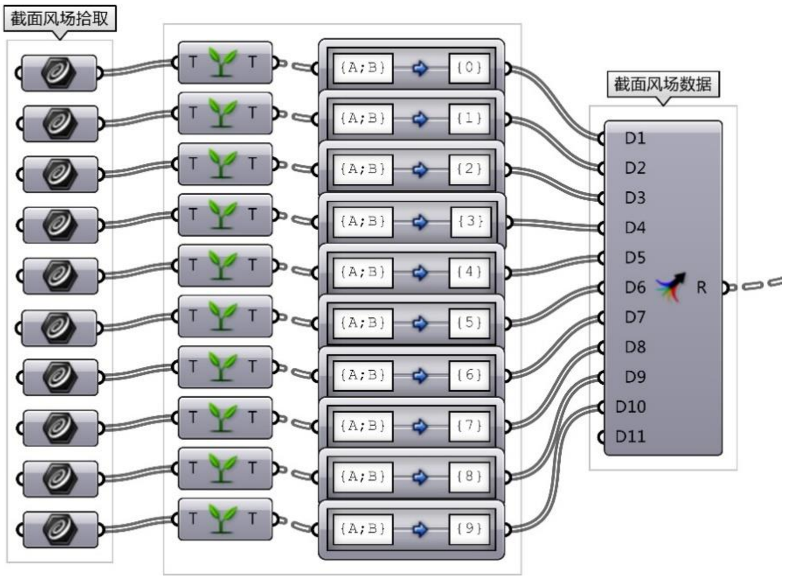


Chart 4-35 Shape remodeling procedure 2: Sectional wind field vector quantity picker

(3) Control section generator: it aims to generate the section of controlling the architecture's shape optimization, and based on which, to get the generated and optimized sectional control line.

(4) Wind field particle simulator: to get the wind curve influencing the architecture's shape optimization, it is necessary to transform the vector data of the sectional wind field which is imported through Ecotect, which is the purpose of wind field particle simulator. Its working principle is as follows: first, a particle launch panel is set on one side through which the prevailing wind will goes into the base, and then according to specific time intervals, the panel will launch particles to the base. When the particle goes through the sectional wind field, its motion state will be changed by wind vector. Under the accumulation of multi-group vectors, the motion curve of the airflow will generate in the interface, which will be recorded as the basis of the shape optimization in next step.

(5) Section control line generator: based on the wind curve obtained in the previous step, from the rectangular section control line, hitch point is projected to the nearest wind curve and connected with it. The length of the pull line determines the magnitude of the pulling force. Under the action of the pulling force, the control line of the rectangular section is transformed into a streamline shape after its response to the wind curve.

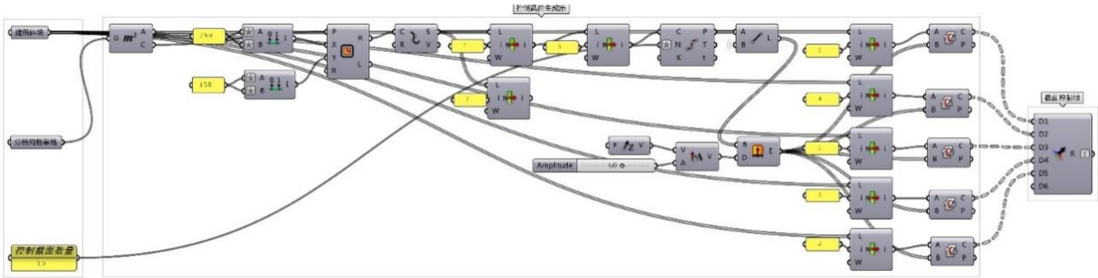


Chart 4-36　Shape remodeling procedure 3:　Control section generator

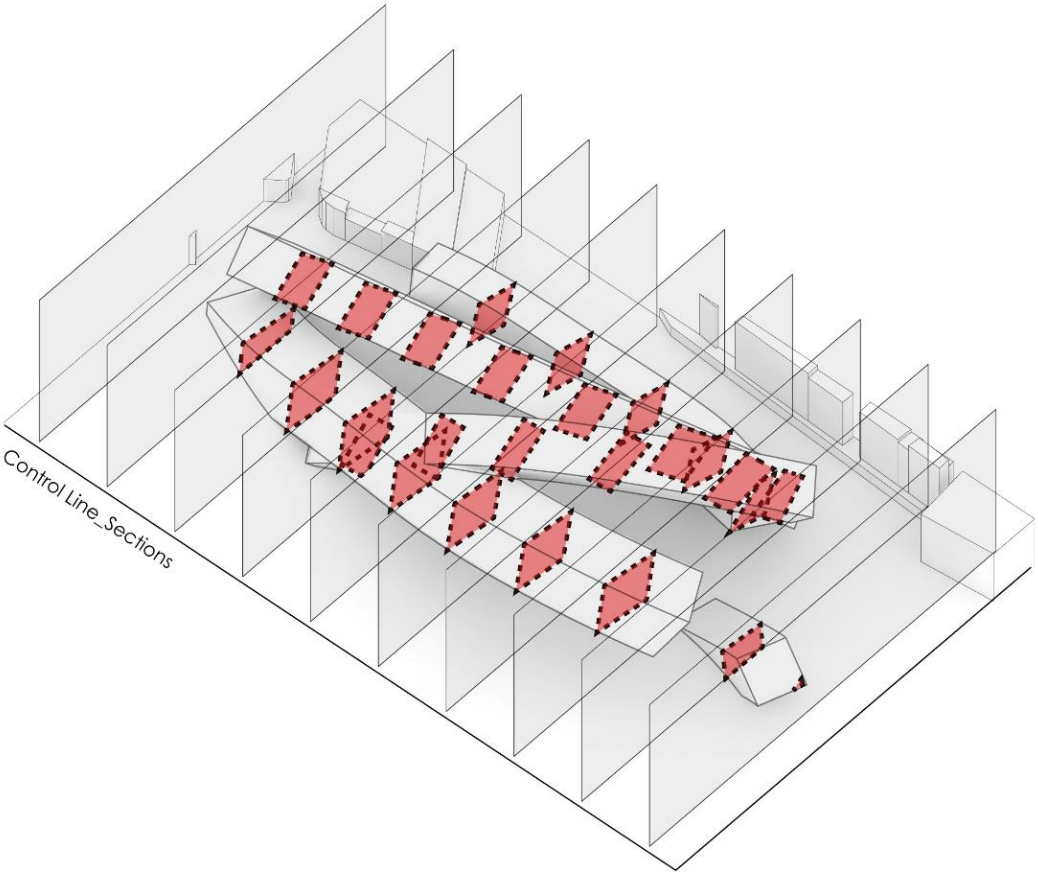


Chart 4-37　Control section

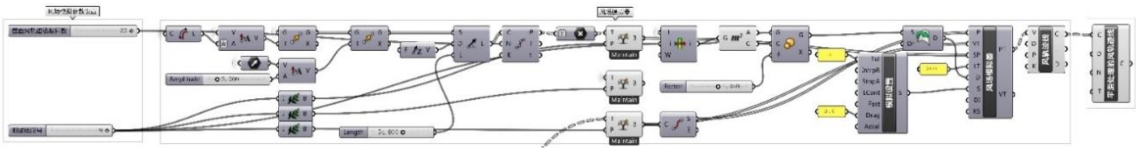


Chart 4-38 Shape remodeling procedure 4:　Wind field particle simulator

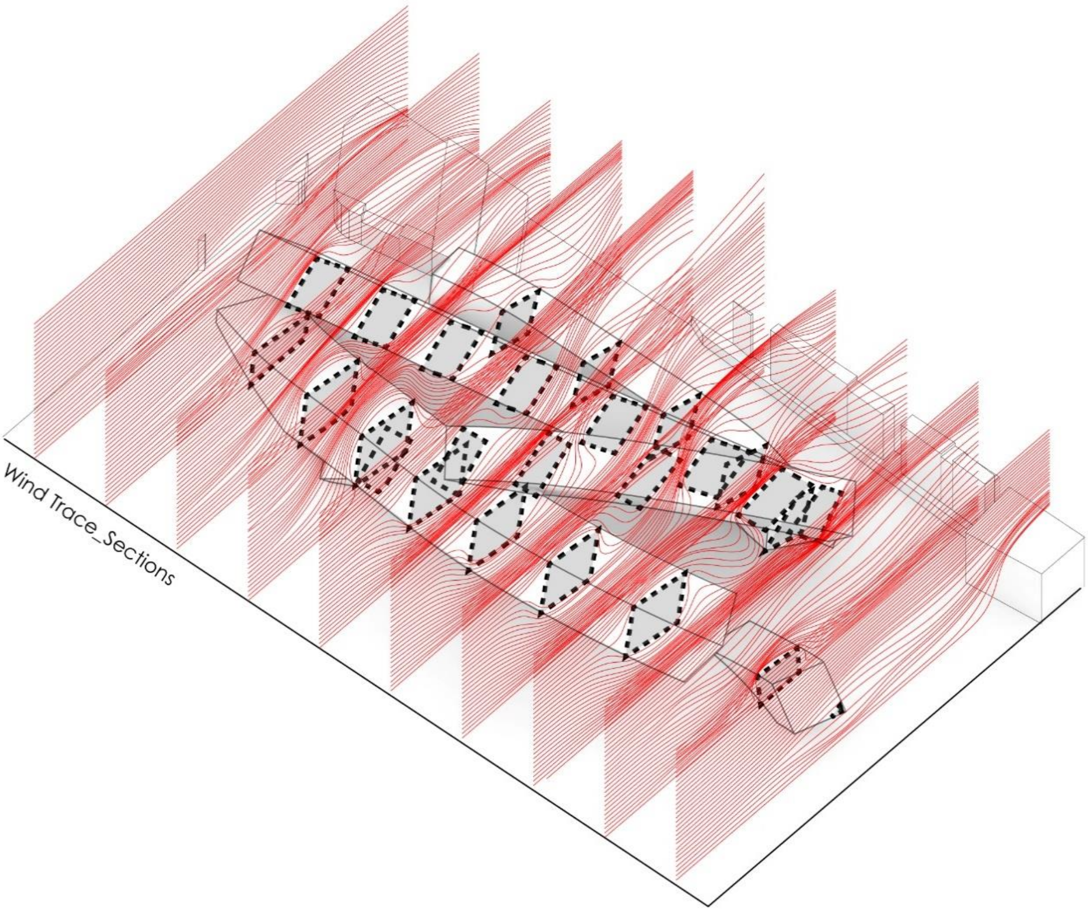


Chart 4-39: Locus Curve of Wind Field

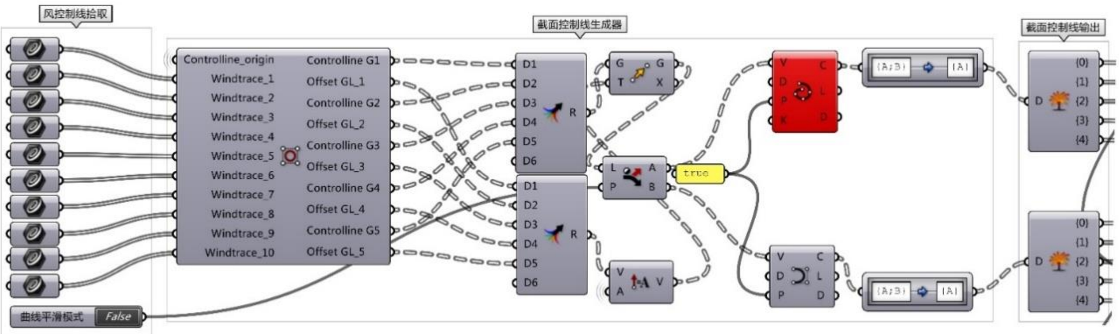


Chart 4-40 Shape remodeling procedure 5: Section control line generator

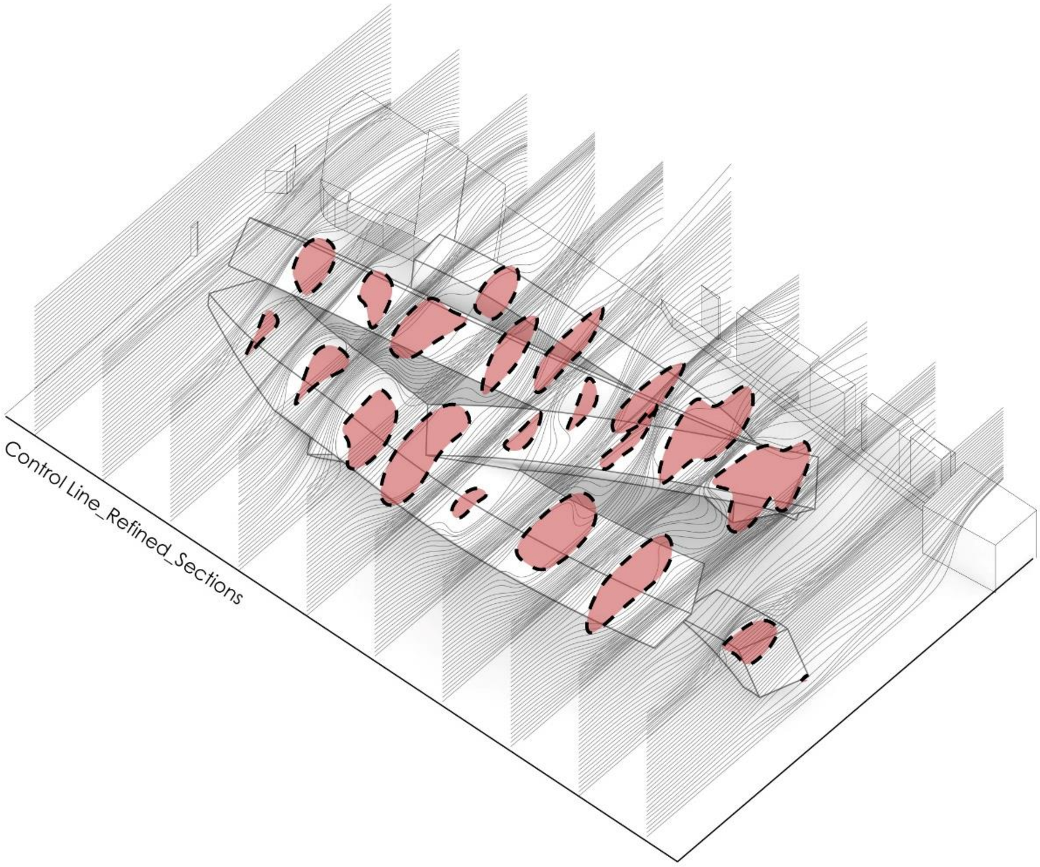


Chart 4-41 Section control line of the building

（6） Surface reconstructor: After the refined generation phase, the generated shape will be further optimized based on certain environmental factors and the subject for environmental performance evaluation must be a complete geometric shape. Therefore, the function of this process is to regenerate the influenced section control curve into the architectural shape so as to be prepared for the shape optimization in next step.

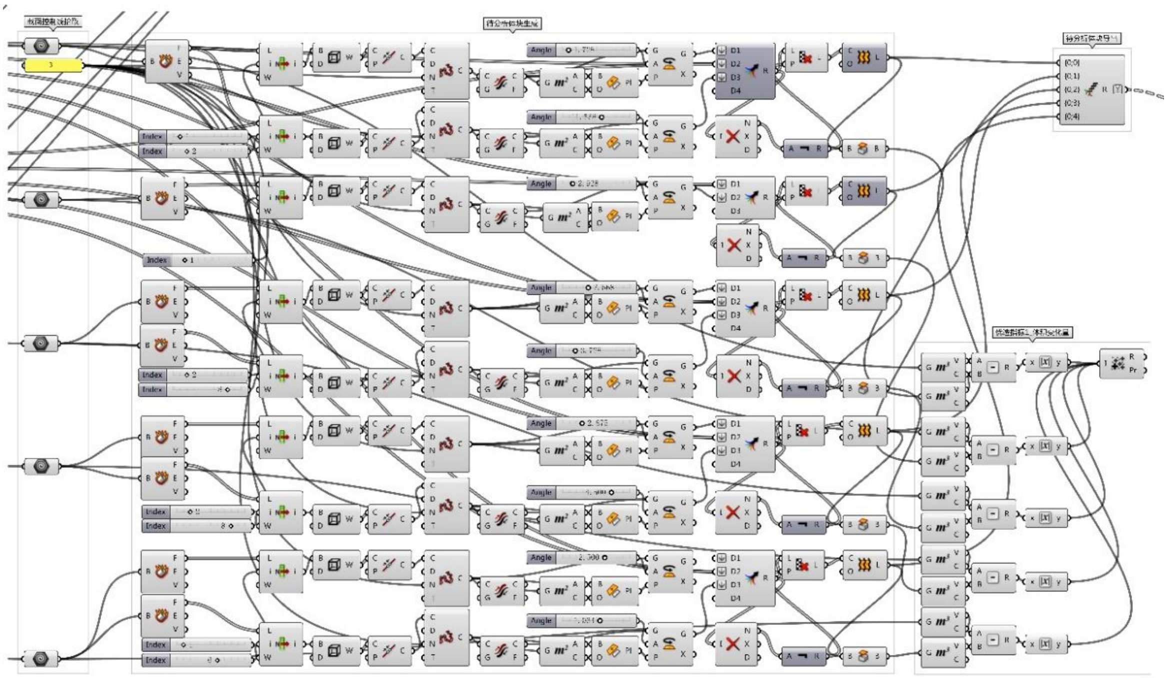


Chart 4-42 Shape remodeling procedure 6: Surface reconstructor

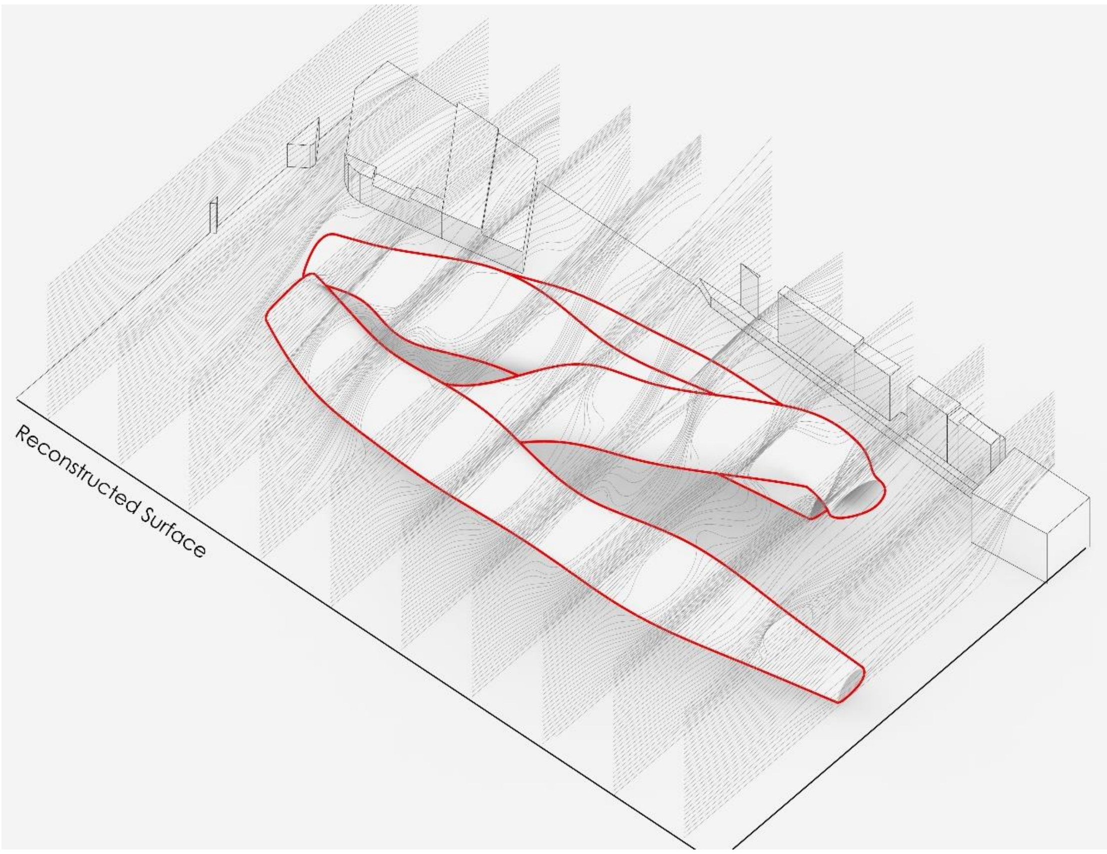


Chart 4-43 Reconstructed architectural shape

So far, the remodeling of the initial block prototype of the building under the influence of wind environment has been completed. From the remodeling procedure above, we've got the streamline architecture shape based on wind environment of the site. Next, we will optimize it by introducing the sunlight factor.

4.4.2 Shape optimization

The streamlined architectural shape has fully taken the response of "wind" environment factor into account, but relative to a perfect design, there still exist some defects to be optimized and adjusted. Through analysis, it is found the following three aspects can be optimized: firstly, as the shape has been operated under the key impacting indicator of wind environment, it is necessary to involve sunlight factor into the process of shape optimization so as to promote its overall environment performance. Secondly, as the remodeling logic is the operation and adjustment based on the section shape, in the generation process, it is hard to avoid the loss of mass. As a result, it is hard to satisfy the needs of the functional area. Thirdly, because of the adjustment of the section shape in last step, some parts of the shape experiences morphological mutation, which leads to the state of "crane neck" and "distortion". This is unfavorable either from the perspective of usage or from the perspective of aesthetics, so it needs to be avoided. At the same time, in the detail design phase of the shape, its relation with the surrounding space available should be considered.

Based on the four aspects of analysis above, the shape optimization logic is established as follows:

(1) The building should try to be equipped with the property of self sun-shading, so its side elevation is expected to receive as little solar radiation as possible.

(2) The area change of the building's section sequence means the smoothness degree of the shape. The smaller the change is, the smoother the block is.

(3) There is an area difference between the optimized architectural block and the original block generated under the strict control over its functional area. This area difference means its non-correspondence between the shape mass and the task requirements. The bigger this area difference is, the more obvious the non-correspondence is, and vice versa.

(4) The city square under the building should try to be in the shadow of the building's sunlight all year round.

On the operation level, the logic above is composed into an optimizing control program, which is composed of six sub-programs: section control generator of the block, sunlight analyzer, volume change calculator, sectional area variance calculator, underneath shadow rate calculator and Galapagos overall GA searching optimizer. After the generation of the section control point, sunlight analyzer, volume change calculator, sectional area variance calculator and underneath shadow rate calculator are in a parallel connection, all of which together carry out the calculation and output the result to Galapagos overall GA searching optimizer. After establishing the variable relation with displacement vectors of the section control point through standardization, weighing and summary of the four optimizing indexes above, this optimizer will carry out GA to find out the optimum solution subject to the conditions.

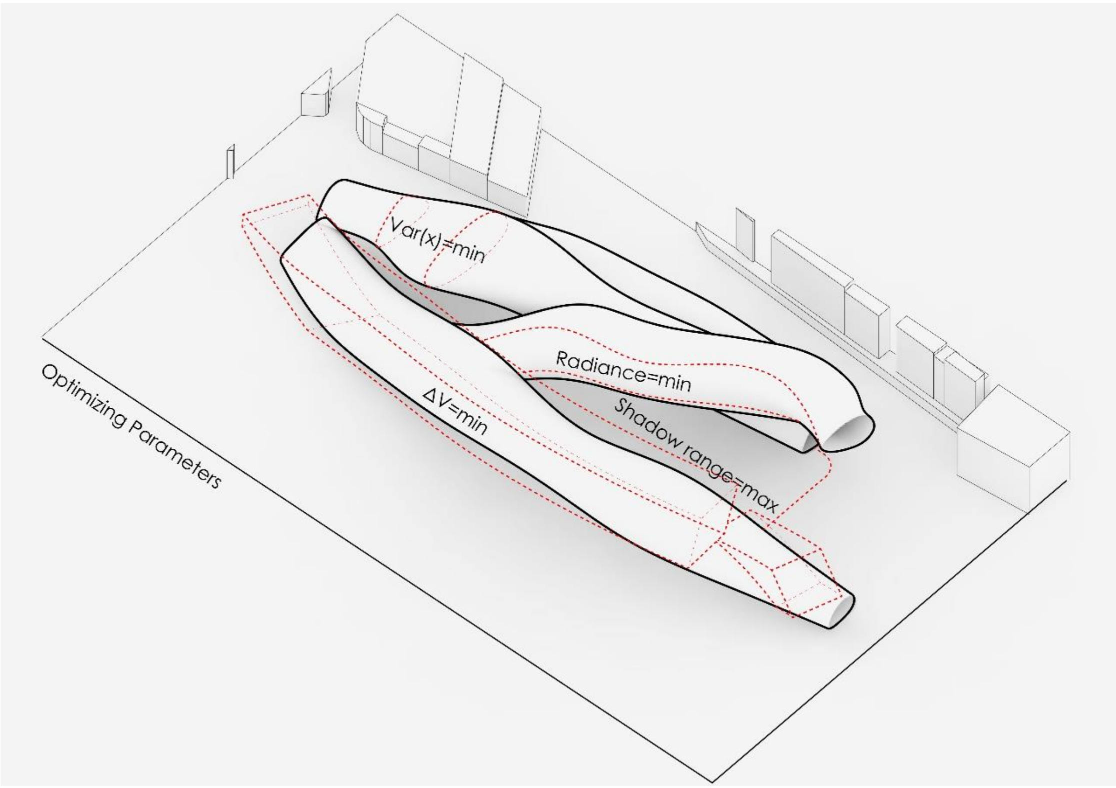


Chart 4-44 Optimizing logic of the architectural shape

(1) Section control point generator: it aims to define the surface's modification control points in the upcoming optimization process as well as the adjustment path of these points under the optimization conditions. In optimization, the shape constantly changes its forms under the control of these constantly adjusted points so as to gradually reach the purpose set by the optimization. This process can be viewed as a converse process of "regenerating from section control curve to the architectural shape" at the phase of shape remodeling. The former is to materialize the control parameters in order to get necessary

environmental simulation data in the optimization process, while the latter is to establish the logic relationship between environmental simulation data and architectural shape adjustment.

In this step, the control section of the architectural shape is reelected, and at the same time, based on its perimeter, it is equally divided into 6 control points, and it is defined that these points can respectively have certain displacement on YZ plane, with ΔYZ as its displacement, which is further output to be prepared for the access to the final Galapagos GA optimizer as adjustment variable.

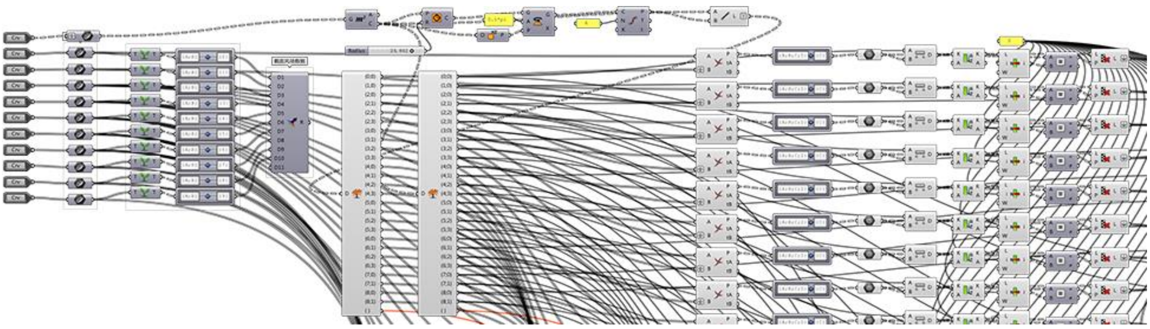


Chart 4-45 Shape optimization control procedure 1- Section control point generator

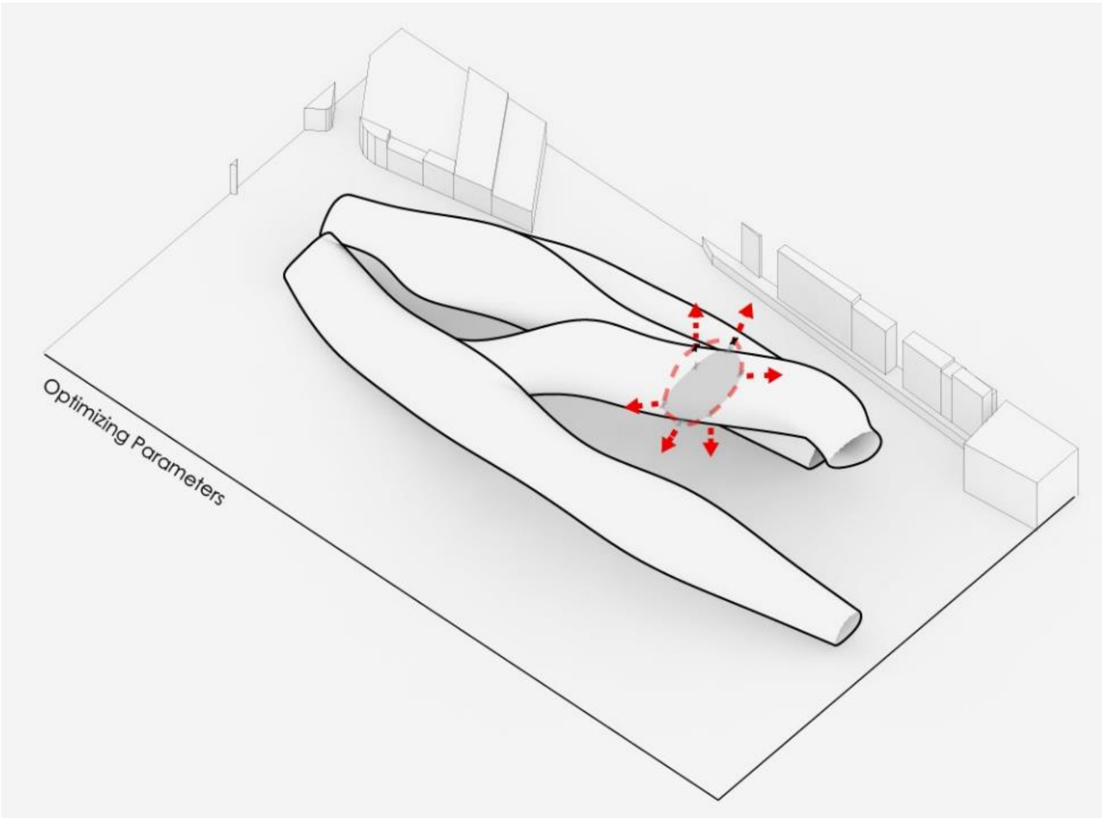


Chart 4-46 Section control point

(2) Sunlight analyzer: The architectural shape is transformed into the analysis grid with certain density and Ecotect is introduced. According to the set analysis parameters,

an analysis will be done on the solar radiation of the surface of shape, the results will be lead into Grasshopper and the results will be displayed in the mode of graphs. Meanwhile, data will be recorded and analyzed in the shape of text, and one-to-one corresponding relations will be established with the analysis grid. Its core is EcoMeshExport, EcoSunPath and EcoSolCal units in the Geco plug, which respectively realized the analysis of grid generation and derivation, generation of solar path line and solar radiation calculation. Major setup parameters include: weather data of the building's location (generally it can be found on the internet [74], besides, in installing Ecotect, the default installation includes a climate file, which can generally be found under its installation directory file \WeatherData), environmental type where the building is located, calculation mode and calculation category, all of which can be selected as required based on specific needs. It needs to be pointed out that as this step is at the refinement phase of the architectural shape, here the analysis grid should be set more intensively so as to achieve more accurate results. But meanwhile, it is noticeable that more elaborate grid will consume more processing resources and computing time.

At the same time, among the obtained analysis results, the side elevation of the sectional block is the sampling part of sunlight value, whose data is output as optimizing index 1. Here the smaller this index value is, the better self sunshade performance the block has.

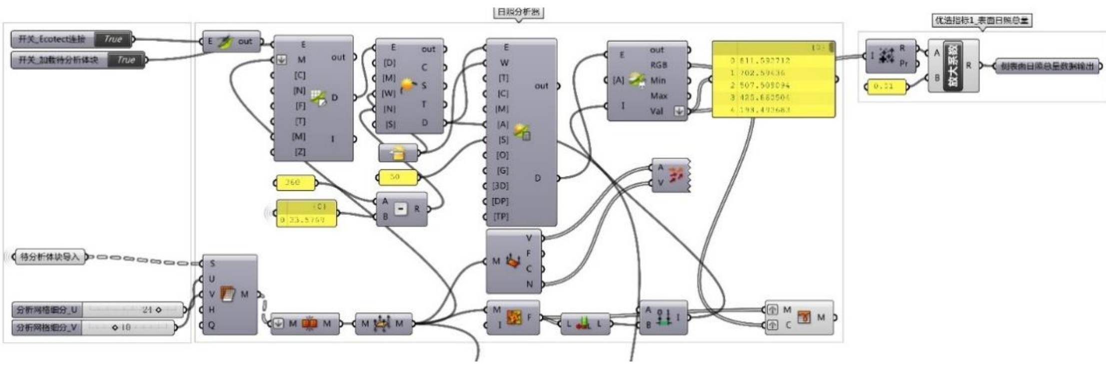


Chart 4-47 Shape optimization control procedure 2-Sunlight analyzer

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[74]. http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm

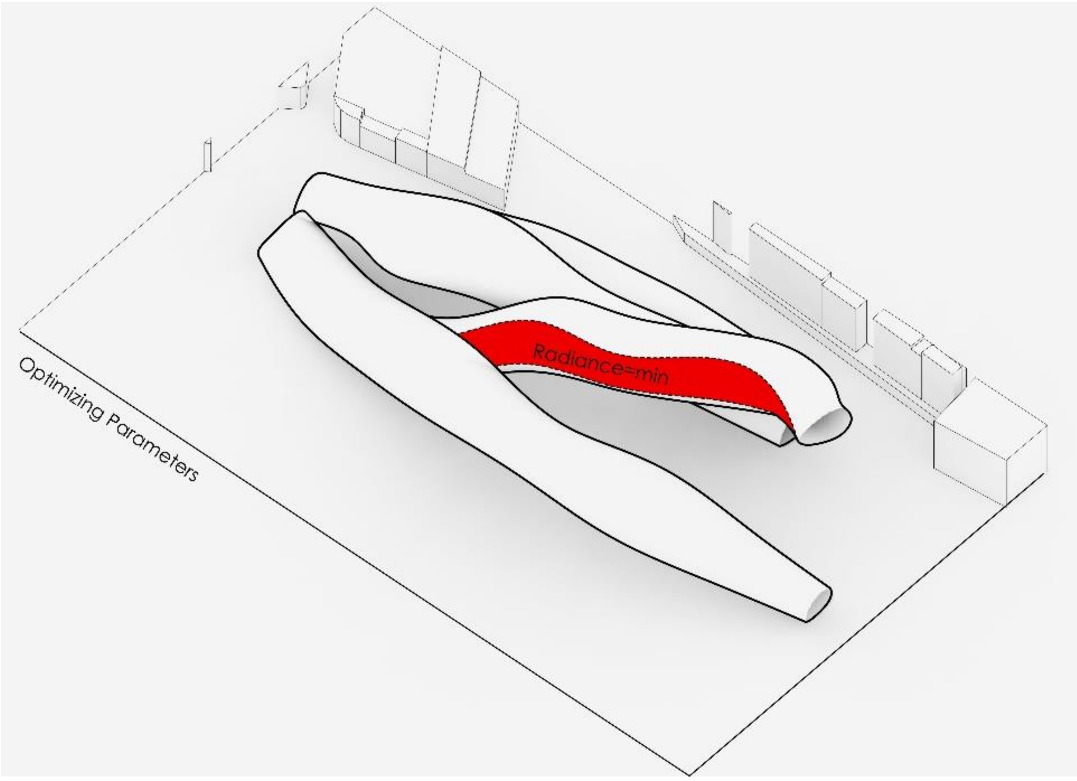


Chart 4-48 Shape optimizing logic 1: Minimum sunshine amount of the side

(3) Volume change calculator: a one-to-one volume comparison is made between the newly generated streamlined block and the square block at the first phase, and the volume difference value ΔV is worked out. The square block is the result strictly generated according to the requirements of functional area, so the smaller its difference value is with the new block, the closer it is with the functional requirements, and the better the generation effect is. Till now, the optimizing index 2 is obtained: volume differenceΔV.

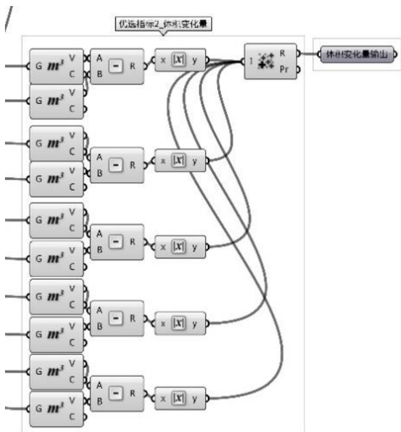


Chart 4-49 Shape optimization control procedure 3: Volume change calculator

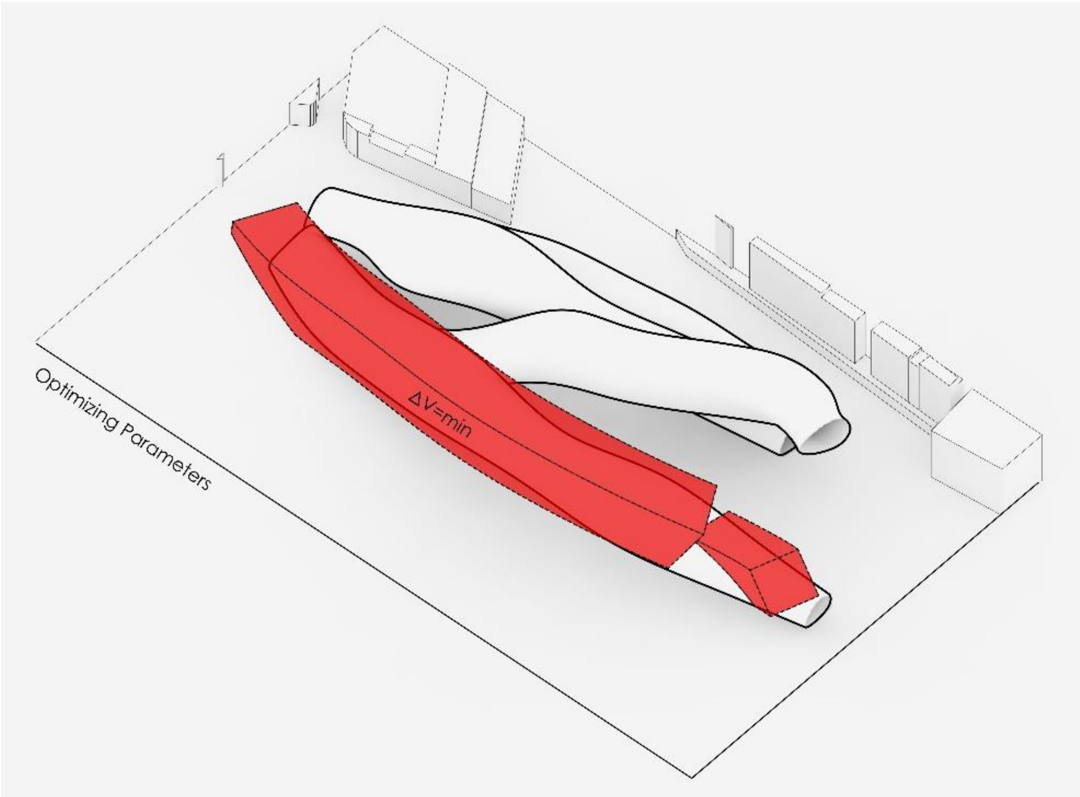


Chart 4-50 Shape optimizing logic 2: Minimum Volume Variation of architectural shape

(4) Sectional area variance calculator: the variance of the sequence signifies the magnitude of the fluctuation among different elements of this sequence. Here it is used to reflect the smoothness of the architectural block. According to the statement above, because of the shape's property of generating from the control section, some mutations appear in certain positions of the shape. Here the sectional area variance is controlled to restrain overlarge data fluctuation so as to prevent the occurrence of morphological mutation to the benefit of usage and beauty. Then sectional area variance Var(x) is derived to be optimizing index 3, which is further derived into optimizing arithmetic unit.

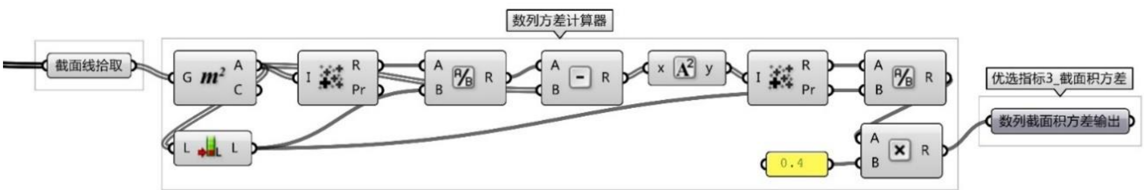


Chart 4-51Shape optimization control procedure 4: Sectional area variance calculator

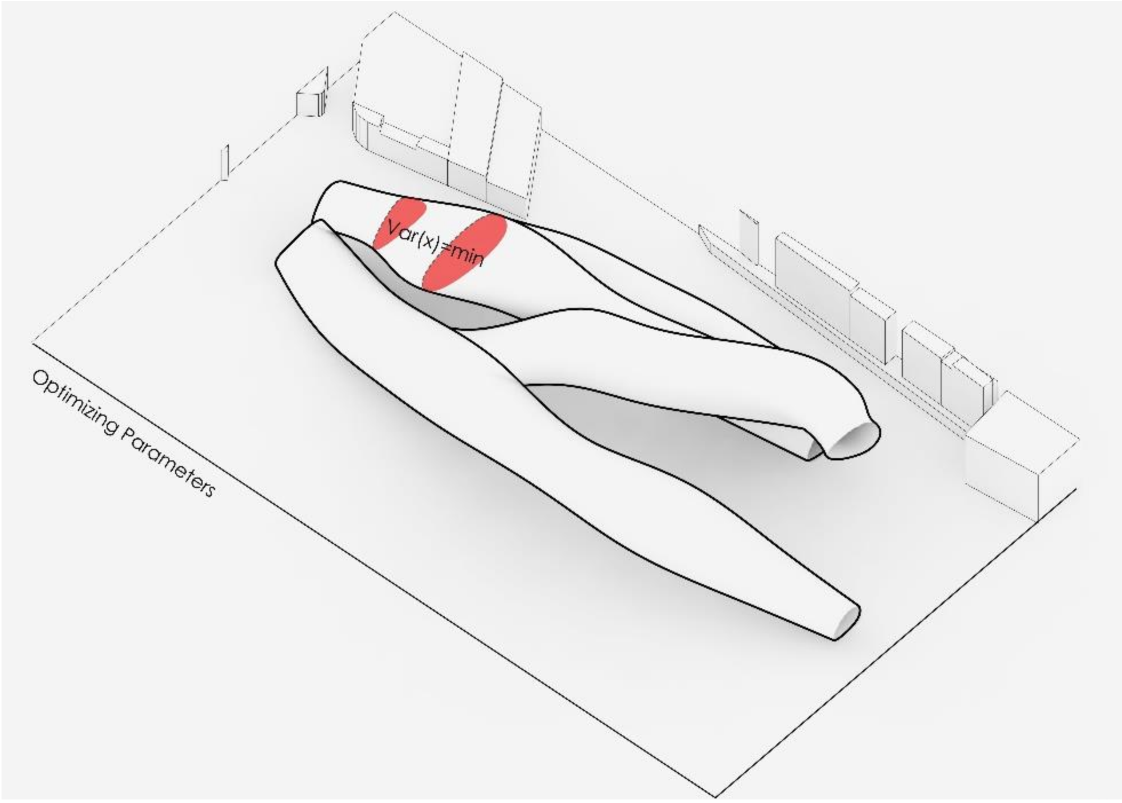


Chart 4-52 Shape optimizing logic 3: Minimum sectional area of the block

(5) Underneath square shadow rate calculator: the city square underneath the mass of the overhung of the building is taken as the test sampling location to analyze the influence of different architectural forms on the shaded effects of the underneath square. The projected area within the scope of the underneath square is taken as evaluation factor 4, which is derived to Galapagos optimizing arithmetic unit. As the environment of the base is relatively hot, it needs better shield from sunshine, so the maximum projected area is the best.

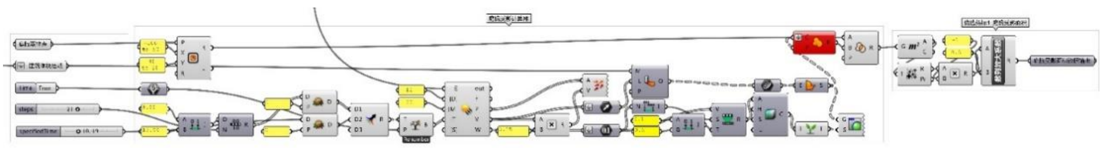


Chart 4-53 Shape optimization control procedure 4: Underneath square shadow rate calculator

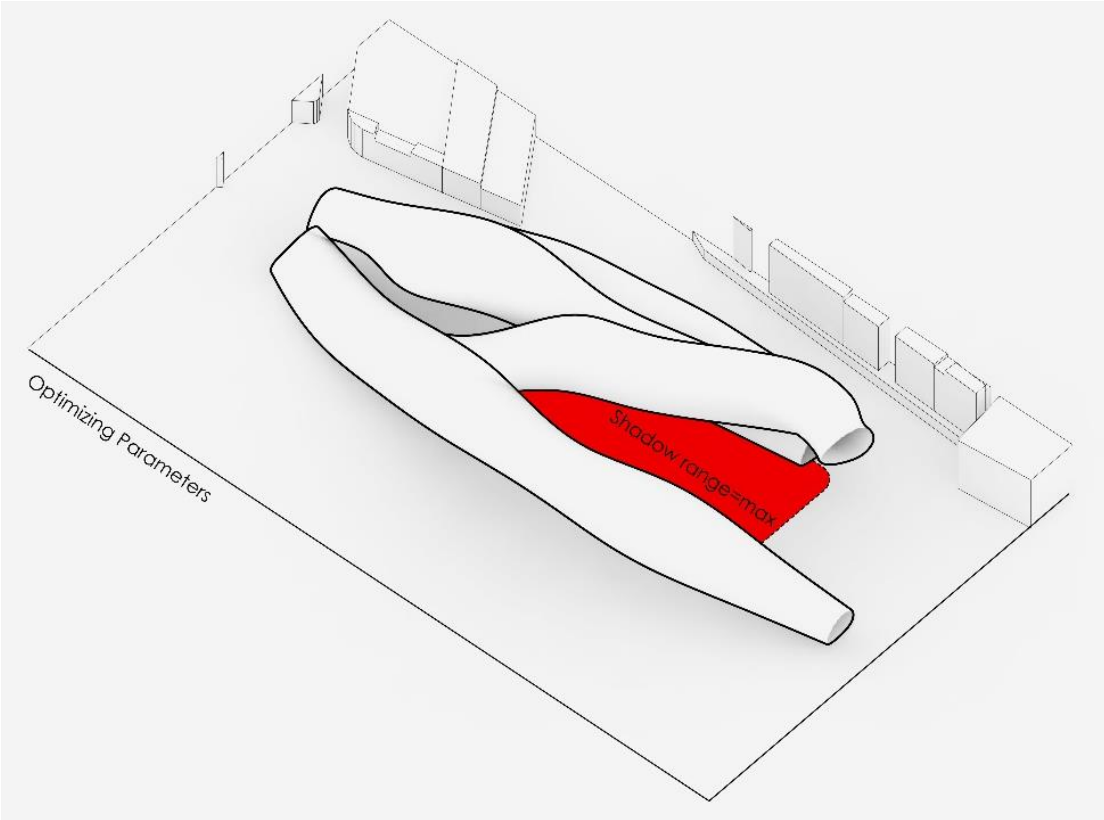


Chart 4-54 Shape optimizing logic 4: maximum shadow area of the underneath square

(5) Galapagos overall GA searching optimizer: the four groups of evaluation factors derived from the arithmetic unit above are integrated and weighed to shape a single evaluation parameter, which is switched into Galapagos. At the same time, the optimization variables are assigned to the control points generating from “sectional control arithmetic unit”. Every control points possesses the displacement value in the direction of Y and Z, so there are totally 300 optimizing variables generated from 150 section control points of 25 section control lines. In the execution process of optimizing and searching program, these 300 optimizing variables will be adjusted, and the variation range of the control variables in every group ranges from -5 to 5. After the setting of the convergence target (here it refers to the minimum value of the general evaluation factors), the GA Search will be started.

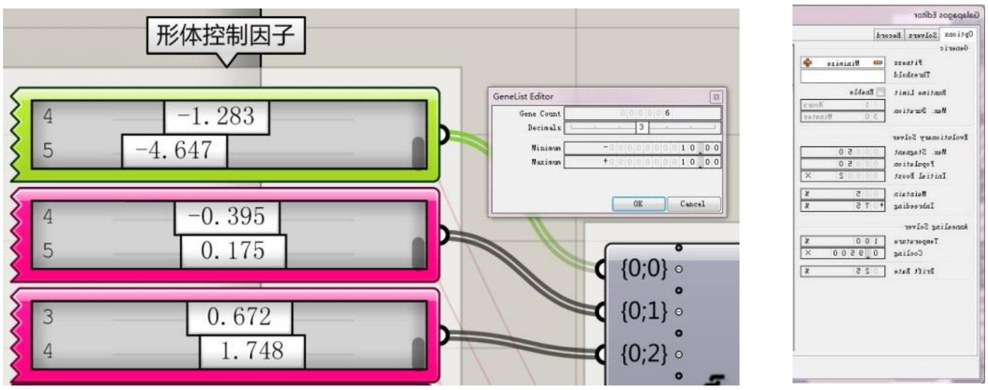


Chart 4-55　Galapagos 300 optimizing variables gene pool

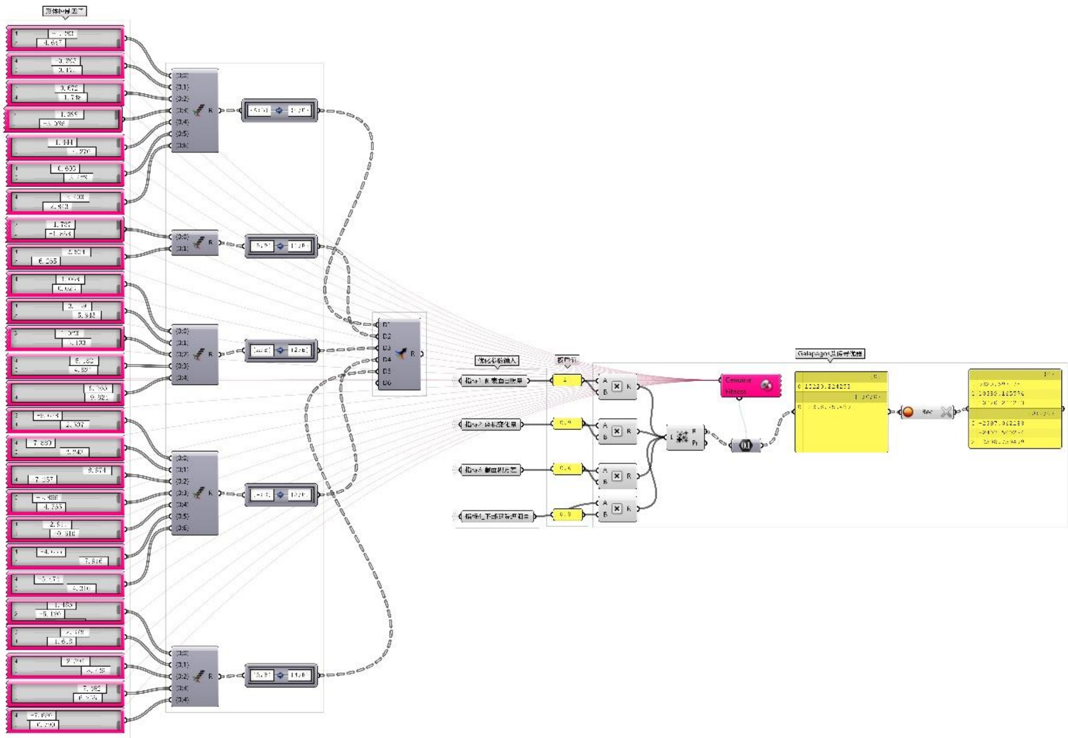


Chart 4-56:　Shape optimization control procedure 6: Galapagos overall GA searching optimizer

The principle of GA has been explained in Chapter 3, so we will not go into details again here. From the optimizing search atlas, we can see that in the initial stage of the optimizing search, the value range of optimizing factors is relatively dispersed. After the iteration of 5 to 10 generations, since the 50th generation, the fluctuation of the optimizing variables and evaluation parameters have been very small, so it can be thought it has approached the optimal solution.

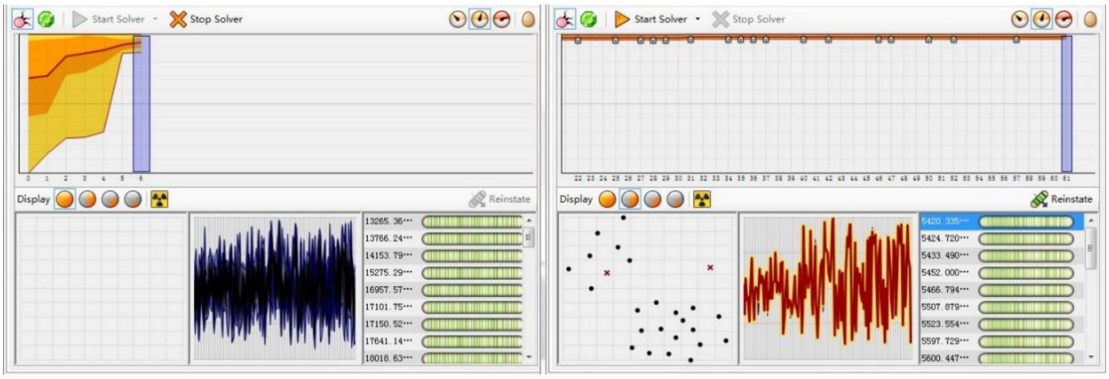


Chart 4-57 Galapagos GA optimizing search process 1

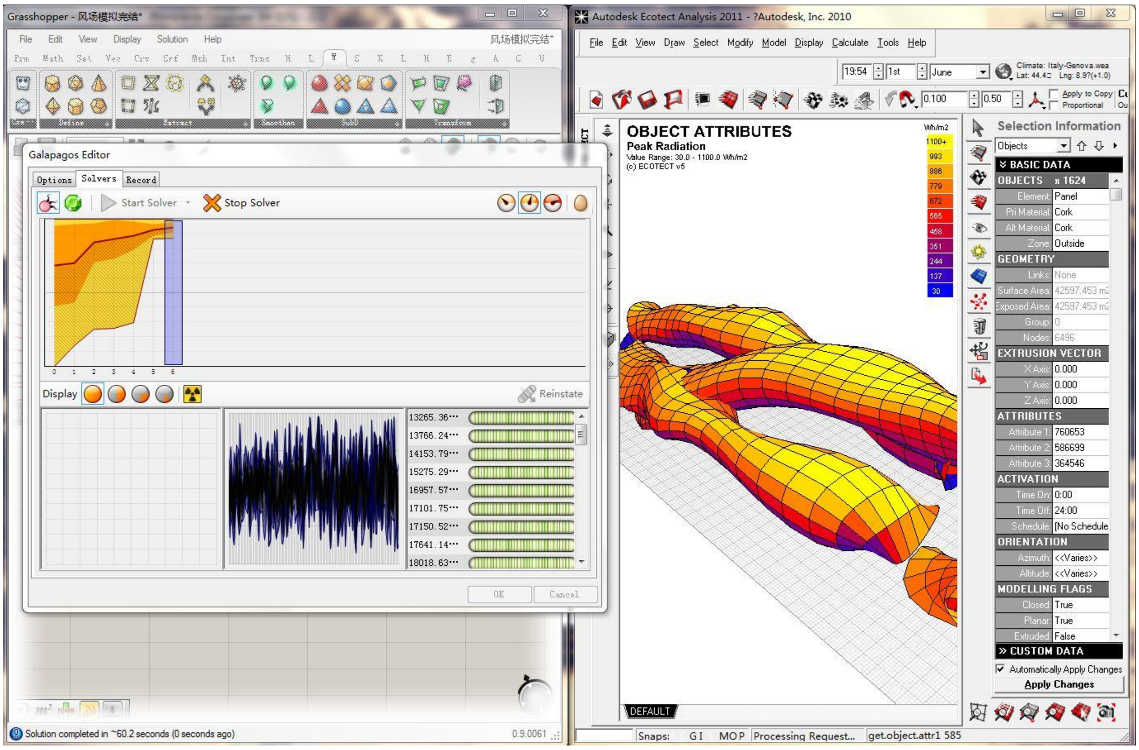


Chart 4-58 Galapagos GA optimizing search process 2

In this operation, there are totally 61 generations of iteration in Galapagos, which takes 41 hours in total. The value of the parameter of the final result is 5420.335. The optimizing outcome is as follows:

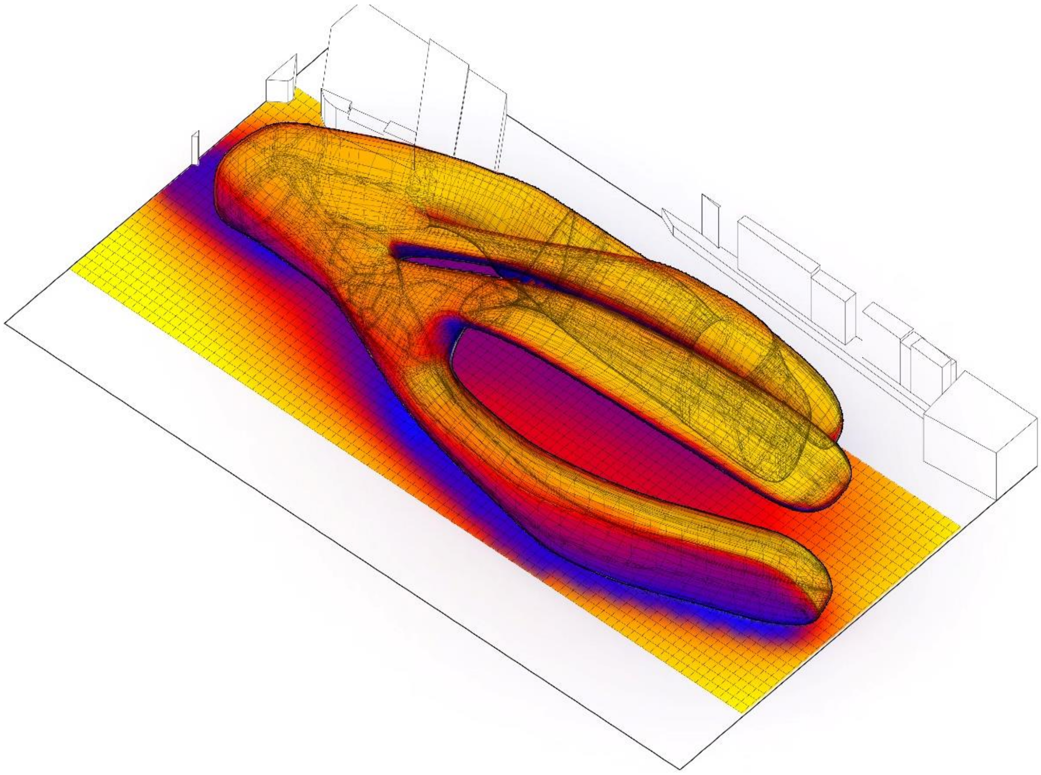


Chart 4-59　Final results produced by shape optimization

In the process of the execution of the computer automatic control system, 821 arithmetic units are invoked, which can be divided into shape remodeling and shape optimizing, whose expected goal is realized through the program of 12 large units.

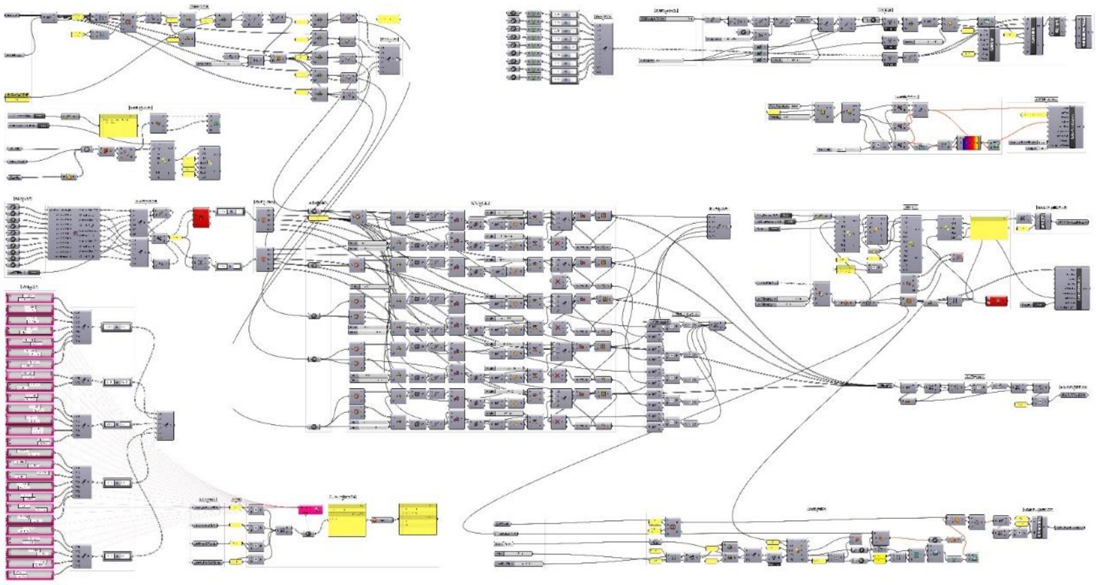


Chart 4-60 Program group collection at the phase of shape refinement

4.4.3 Manual modification

So far, the computer generation of the shape's refined parts——the optimization process has been finished. In this process, by applying the influence of environmental factors such as sunlight, self sunshade efficiency as well as design requirements including functional area difference and shape smoothness, the optimized architectural shape is obtained. However, because of the limit of the algorithm and the small mistakes in program operation, in terms of an architectural design scheme, there are still some unsatisfying defects to be manually fine tuned by the designer according to specific circumstances. For example, increasing the interface channel between bodies and modifying the unsmooth part of bodies. After modification, the final result of this phase is gains.

Then it is manually led into Ecotect for verification, and it can be seen:

(1) Seen from the section, the architectural shape is a in a reverse T-shape, and almost all side elevations are within the shadow zone of its shape. It is obviously the result of the optimizing logic "the side elevation receives minimum sunshine".

(2) In the city square under the building's block, except for a few areas, most of them are covered by the shadow of the upper architectural shape. The shaded effect is quite good, and optimization algorithm of "city square shadow rate" operates well.

(3) There is no drastic distortion and mutation to the architectural shape and the control effect of the "section variance" is well reflected.

To sum up, the working state of every group of procedures at the phase of shape refinement is very good. The three working procedures including shape remodeling, shape optimization and manual modification are closely connected and effective.

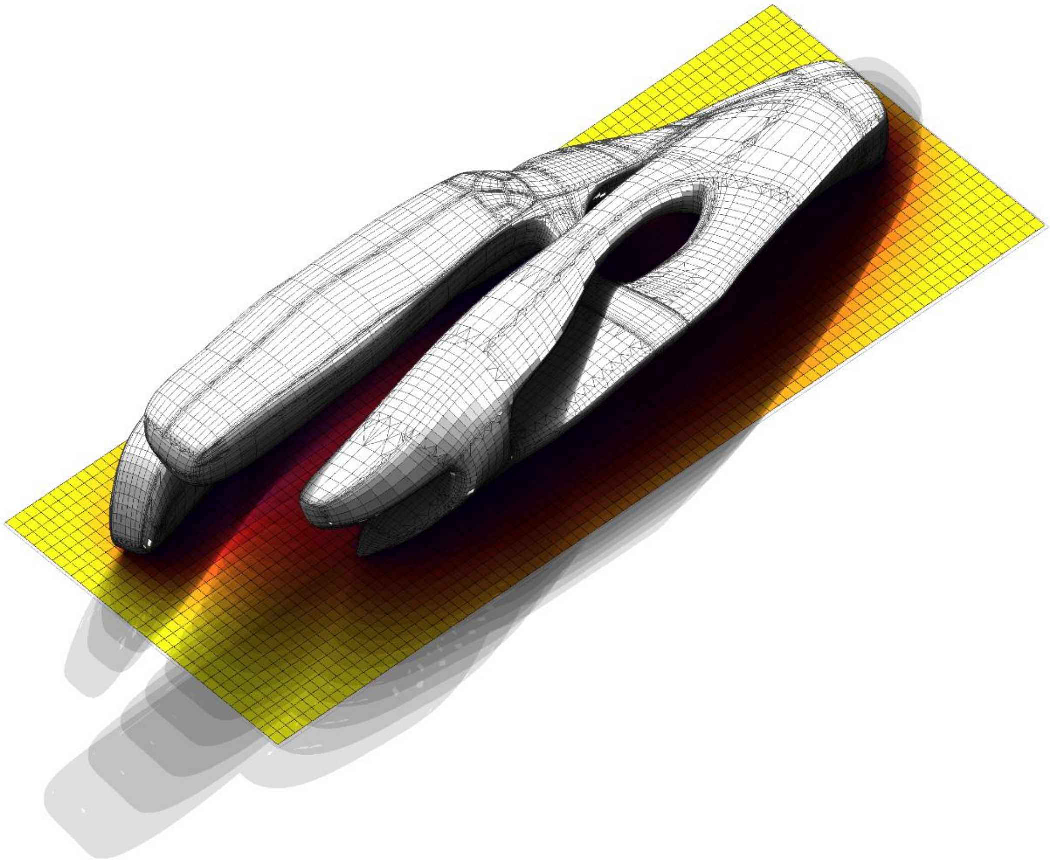


Chart 4-61 Ecotect Verification shape adjustment result: Shadow scope

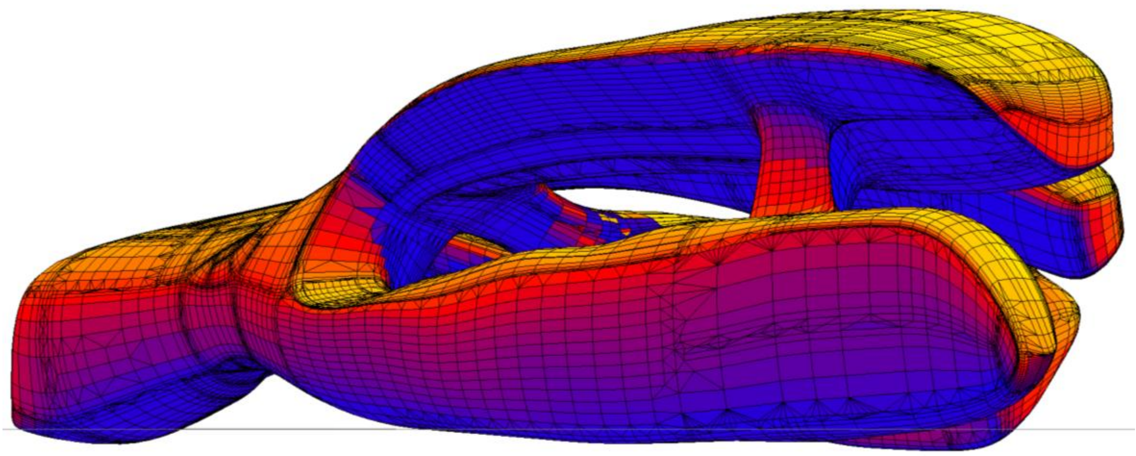


Chart 4-62 Ecotect Verification shape adjustment result: Surface solar radiation 1

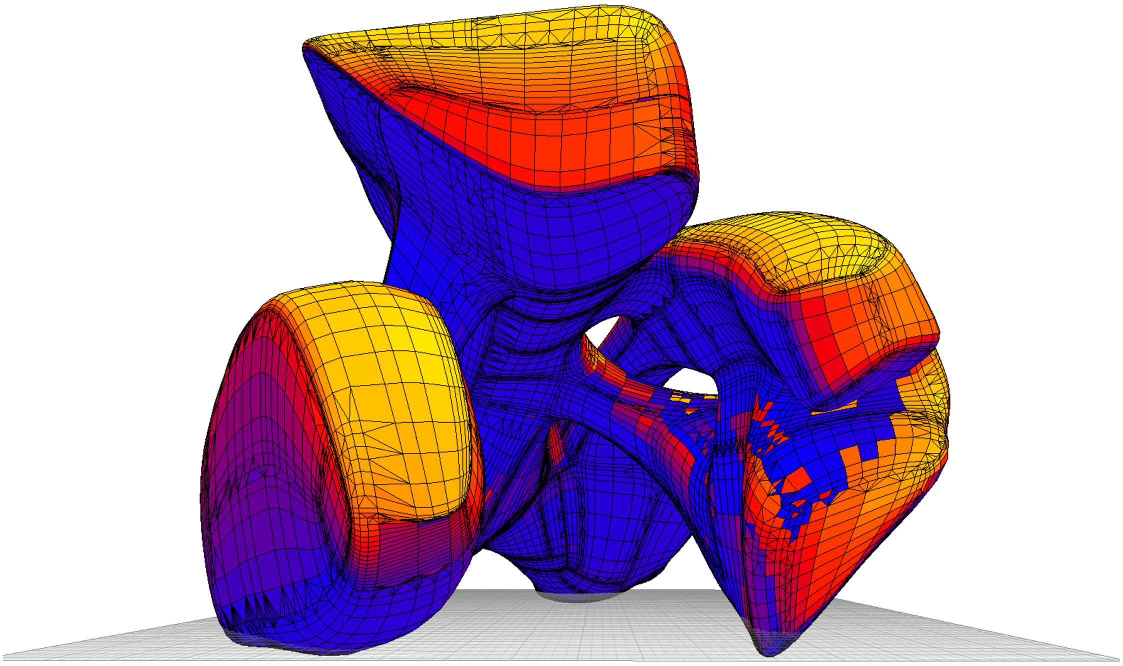


Chart 4-63 Ecotect Verification shape adjustment result: Surface solar radiation 2

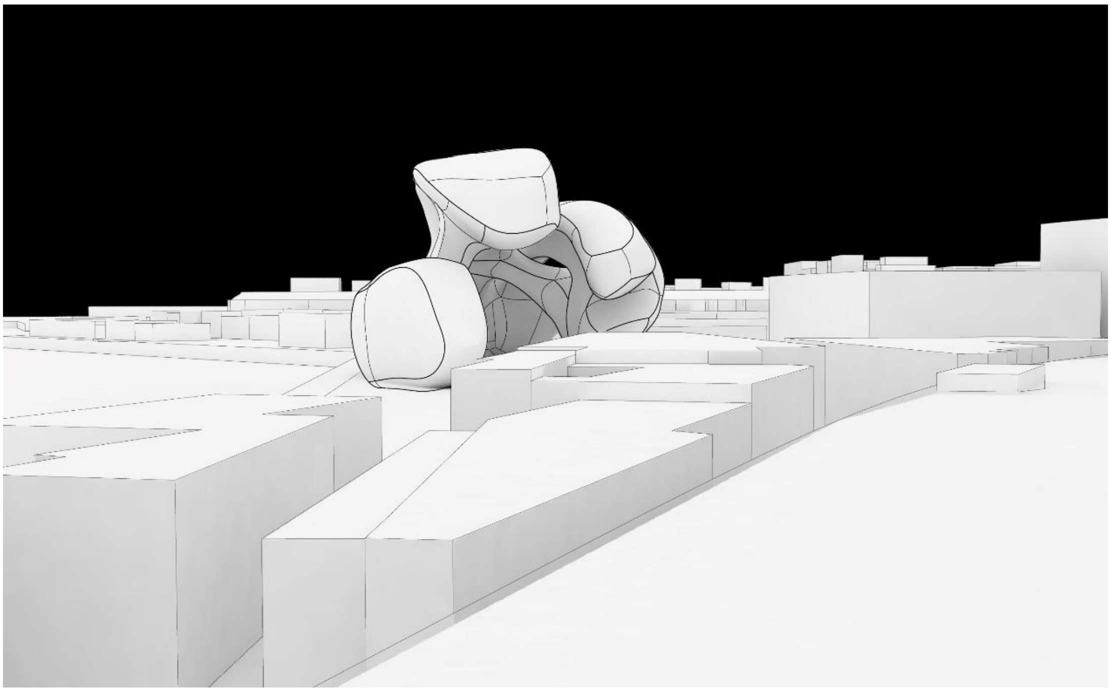


Chart 4-64 Final result of the shape at the refinement phase: Angular perspective of elevated road

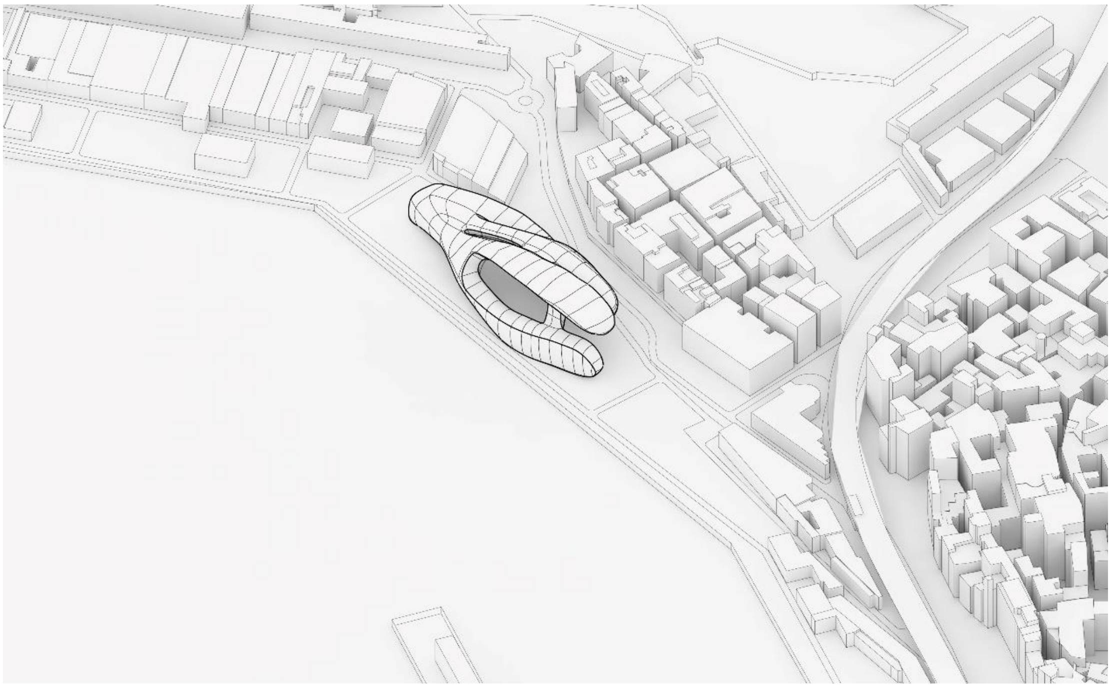


Chart 4-65 Final result of the shape at the refinement phase: Axis measure

4.5 Detail design

After the confirmation of the architectural shape, now let’s come to the final step of this design——detail design. At this phase, based on the architectural shape generated in at the previous two phases, according to internal functional requirements and external environment factors, the thesis will have an overall consideration of the building’s window size, window position as well as the surface’s shape and logic.

4.5.1 Surface generation

A complete surface of the shape can make the architecture more beautiful and equip the architecture with a better integrity, and meanwhile, its space with the building can be used as an air space so as to improve its thermotechnical performance. Based on the considerations above, the author decides to set up external surface for the architectural block. Firstly, a design concept strikes the designer, that is, the design idea based on “interweaving of multiple linear functional block”， which focuses on highlighting the linear rhythm in the direction of its long axis and tries to reflect the sense of “linearity, winding and speed” in its surface shape.

Based on the concepts above, the author starts to think about the possibility of combining with functions and prepares to use procedure generation to offer rationality to it. Considering the dominant position of morphological factors, the following generating logic is formulated:

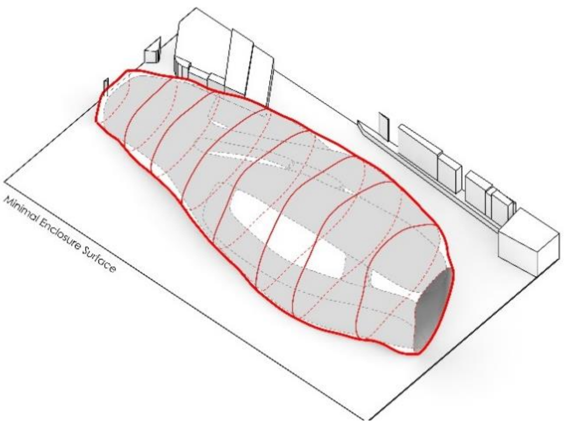
(1) The surface needs to emphasize the shape rhythm of the architectural block, so it needs to be constructed based on the architecture’s existing shape frame.

(2) While generating the surface based on the basic shape frame, it needs to be subdivided into smaller units for the convenience of the adjustment operation of the optimizing procedure.

Next, based on the generating logic above, the author starts to write the control program of surface generation, which includes minimum the coverage face generator and the surface generator.

(1) Minimum coverage face generator: Here Kangaroo mechanical simulation plug-in on Grasshopper platform is used to simulate a flexible coating curved surface to cover the existing architectural block. Because of the function of flexibility, it can be thought that this flexible curved surface is the minimum face to cover the architectural block. And then based on this curved surface, it is further subdivided into 30×30 grids, which aims to provide analysis grids and dada foundation for the surface coverage position and area to be confirmed in the following steps.

(2) Surface generator: This procedure is relatively simple. Its working principle is to select the subdivided grid generated above as the reference face of the surface according to the maximum value of 50%. And the data is then derived for the use of surface optimizing procedure.



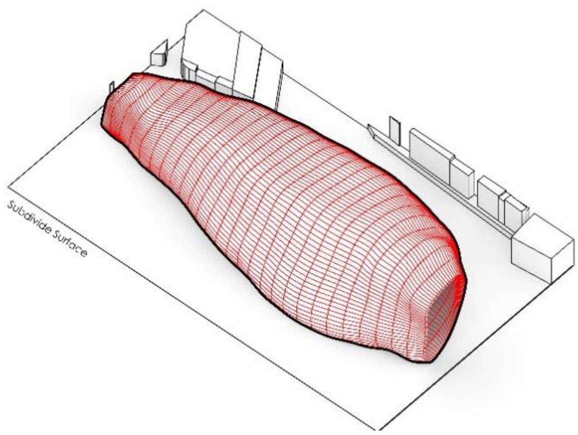


Chart 4-66 Surface generation logic 1: minimum coverage face

Chart 4-67 Surface generation logic 2 Subdivided units of coverage face

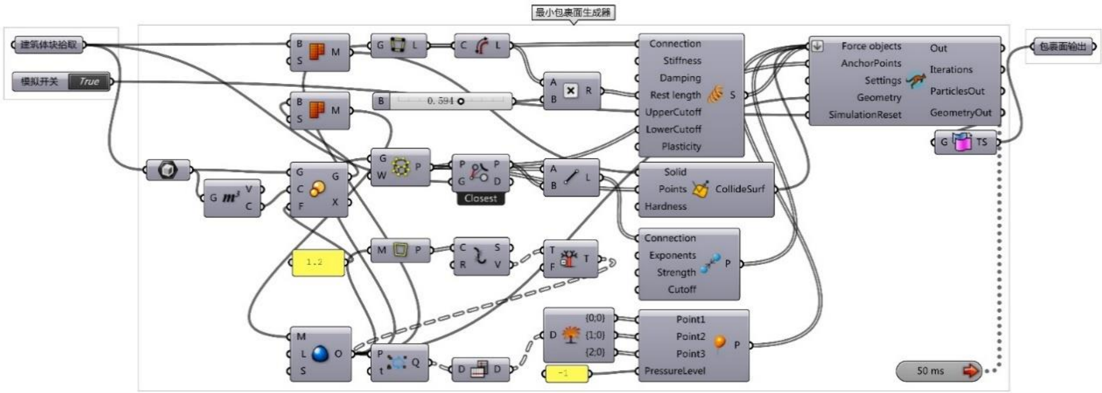


Chart 4-68 Surface generation control procedure: generating of minimum coverage face

4.5.2 Surface optimization

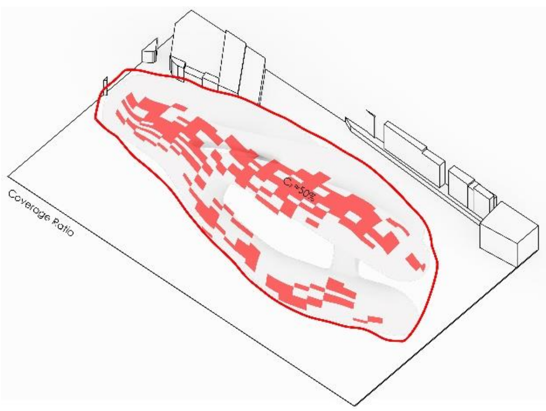
In terms of the surface prototype generated in the previous step, according to the needs, the following optimizing logic is formulated:

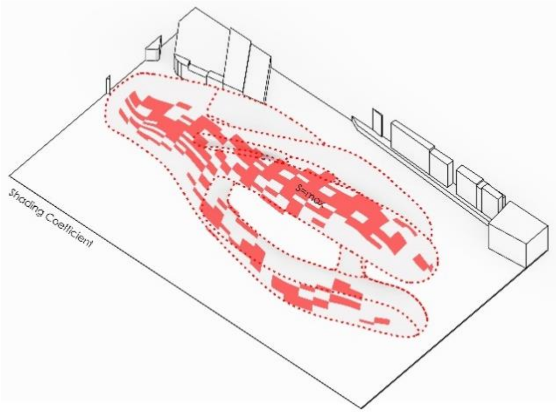
(1) Based on the requirement of transparency, its coverage is limited within 50% of the minimum coverage face of the whole building.

(2) Considering the surface function, its distribution position should try to be set in the place which can cover the parts receiving the severe solar radiation.

(3) Considering the sight of the underneath square, it is limited not to block the block's existing space opening.

Next, based on the optimizing logic above, surface generation control procedure is compiled, which includes surface coverage rate calculator, surface sunshade rate calculator, surface sight blocking calculator and optimization selector.





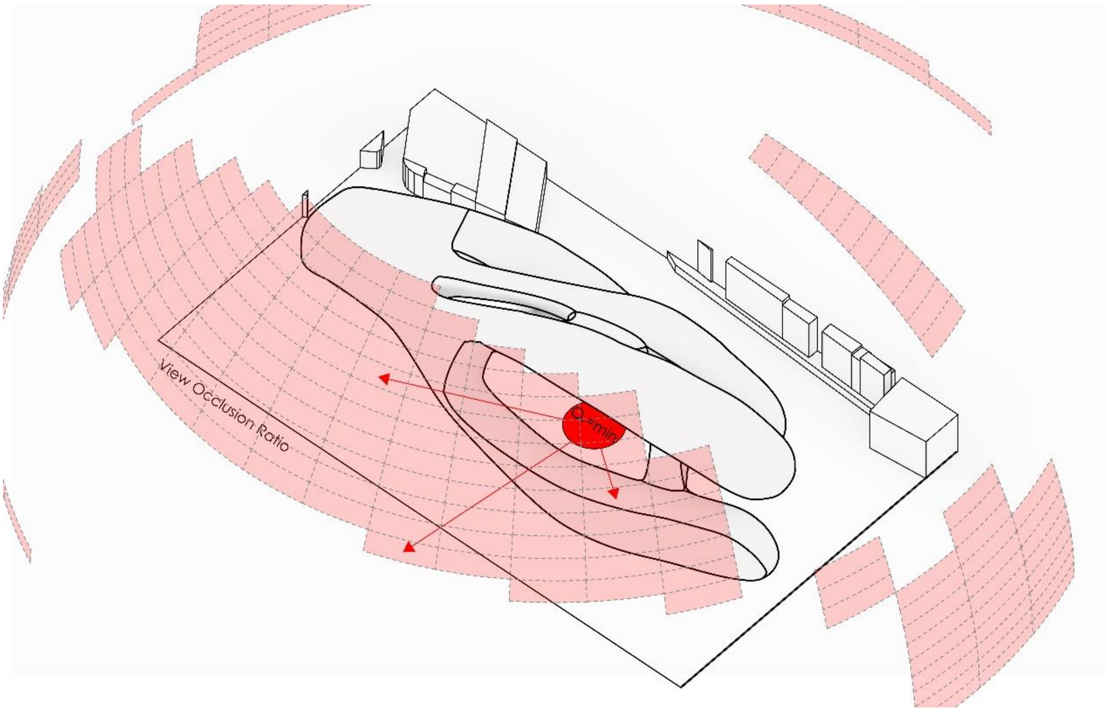


Chart 4-69 Surface optimizing logic 1: the coverage rate is lower than 50% of the area of the coverage face

Chart 4-70 Surface optimizing logic 2: the surface should try to cover the parts receiving the severe solar radiation

Chart 4-71 Surface optimizing logic 3: Minimum blocking of the existing space opening of the architectural block

(1) Surface coverage rate calculator: by comparing the area of the surface and the surface area of the minimum coverage curved surface generated in the previous step, the calculator works out the surface's coverage rate. It is required that the closer it is to the value 0.5, the more it accords with our expectation. Finally, the result is used as optimizing index 1, and led into the optimization selector.

(2) Surface sunshade rate calculator: the working principle of this calculator is to compare the solar radiation valued received by the underneath building under the coverage of the generated surface with the solar radiation measured in the same part. The bigger this difference value is, it means the

better sunshade effect the surface has. Finally, this difference value is used as optimizing index 2, and led into the optimization selector.

(3) Sight blocking calculator: Sight sampling locations are set in the center of the underneath square. By protecting rays to “the celestial sphere” with larger radius through the existing space opening, the blocking rate of the newly generated surface is calculated. The smaller this rate is, it means the smaller blocking the surface on the existing sight. This chart is derived to be optimizing index 3.

(4) optimization selector: Similar to the shape refinement which brings some parts to the optimization selector, here after the standardized collection of the input evaluation index, GA is invoked to conduct iterative refinement so as to finally work out the optimized surface prototype.

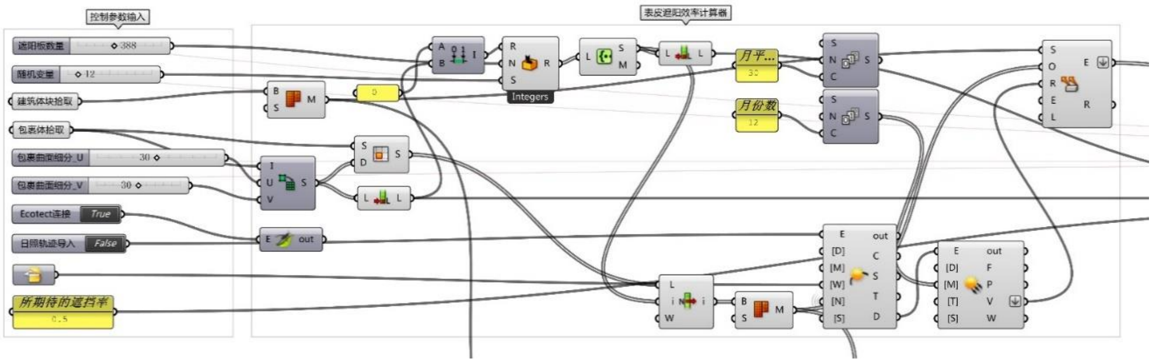


Chart 4-72 Surface Optimization control procedure 1, 2: Surface coverage rate, surface sunshade rate calculator

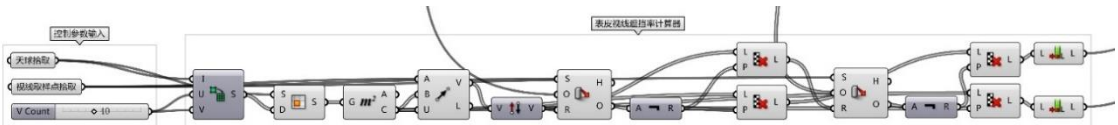


Chart 4-73 Surface Optimization control procedure 3: Sight blocking calculator

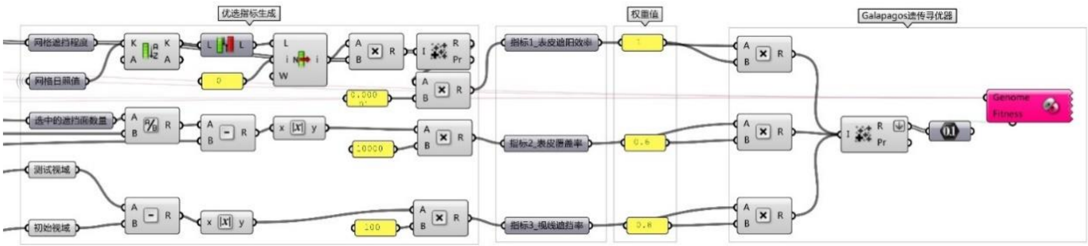


Chart 4-74 Surface Optimization control procedure: Optimization selector

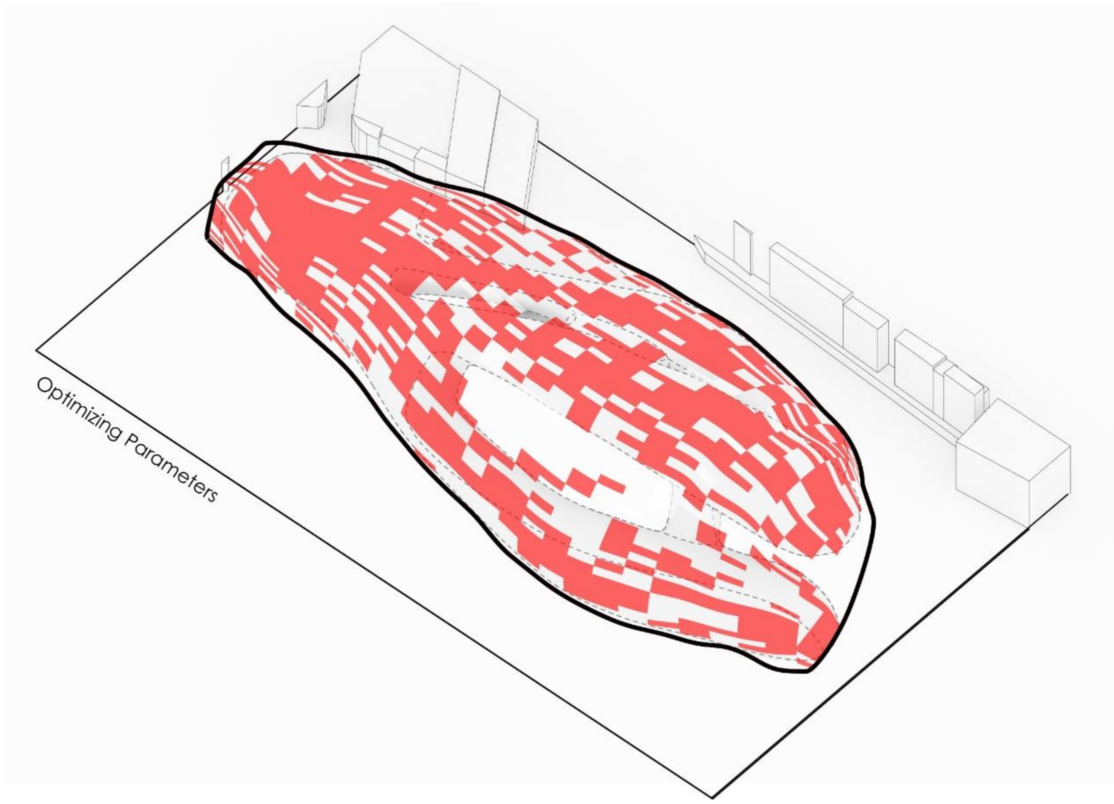


Chart 4-75 Final result generated from shape optimization procedure

So far, the surface shape after optimization selection is obtained. It is not difficult to find that it is just a prototypical generation-optimization research, which is still far from the usage in design. But from this result, we can work out the general distribution range and trend of the architectural surface for the reference of further design.

4.5.3 Final adjustment and brief summary

In the process of this project design, according to different design tasks and purposes, it is divided into four gradually deepened design processes: concept extraction, block generation, shape refinement and detail design. in the shape extraction part, it mainly involves the designer's research and analysis of the base's surroundings as well as the extraction and development of the design concept, and the initial complicated design is subjectively abstracted and translated. After that, in the generation of the block, based on the generation logic of the translated architectural block, by programming, it constitutes self-organizing emergence generation system so as to provide as more possible directions as possible for the project. Based on this, preferential selection driven by environmental performance is carried out. Furthermore, shape remodeling is done based on wind environment and GA-based optimization is done based on the sunlight factor so as to reach the optimal solution. Finally, adjustment and modification are done on the architectural surface, window and final shape based on environmental performance.

As this is the last step for the generation of the architectural shape at the initial phase of the project design, in order to have an adjustment and control over the final presented design plan to a bigger degree, the designer's manual setting is adopted. Based on the surface distribution prototype generated above, manual modeling is done to get the architectural shape with surface design.

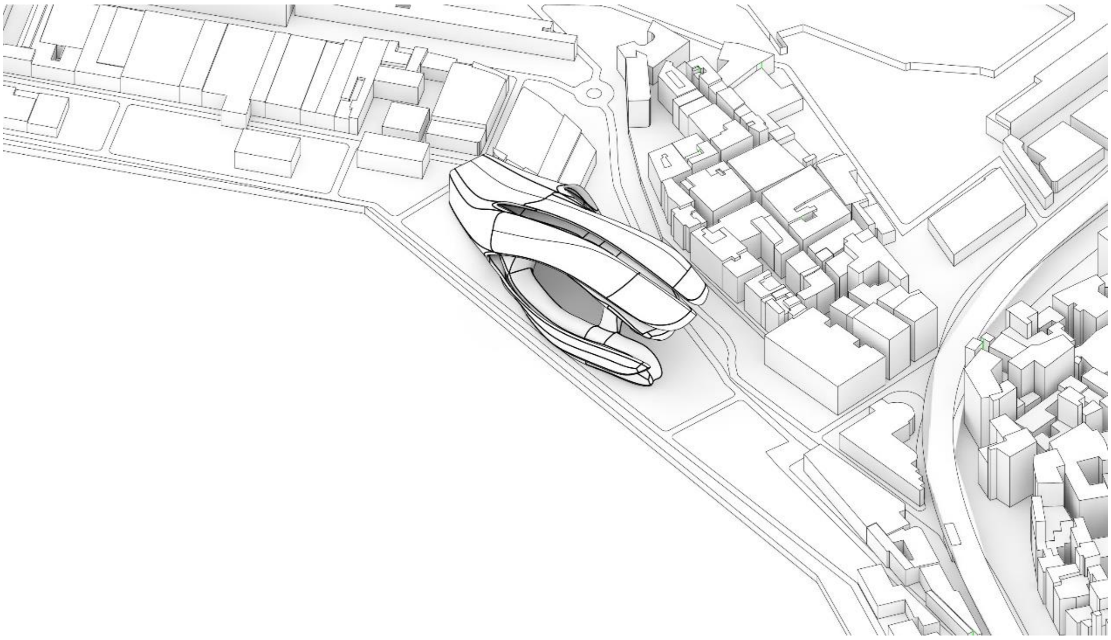


Chart 4-71 Architectural surface shape after manual adjustment and modeling

After that, according to the requirements of the architecture's functions, the design of windowing and surface texture is done on the shape. The final result of this project design is achieved.

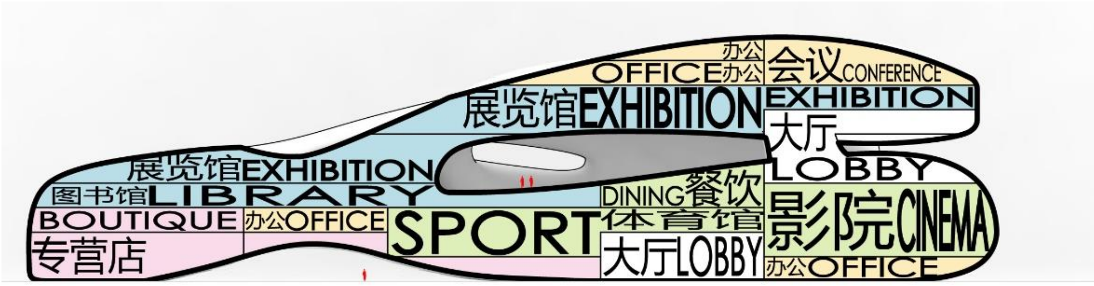


Chart 4-72 Section of architectural function arrangement

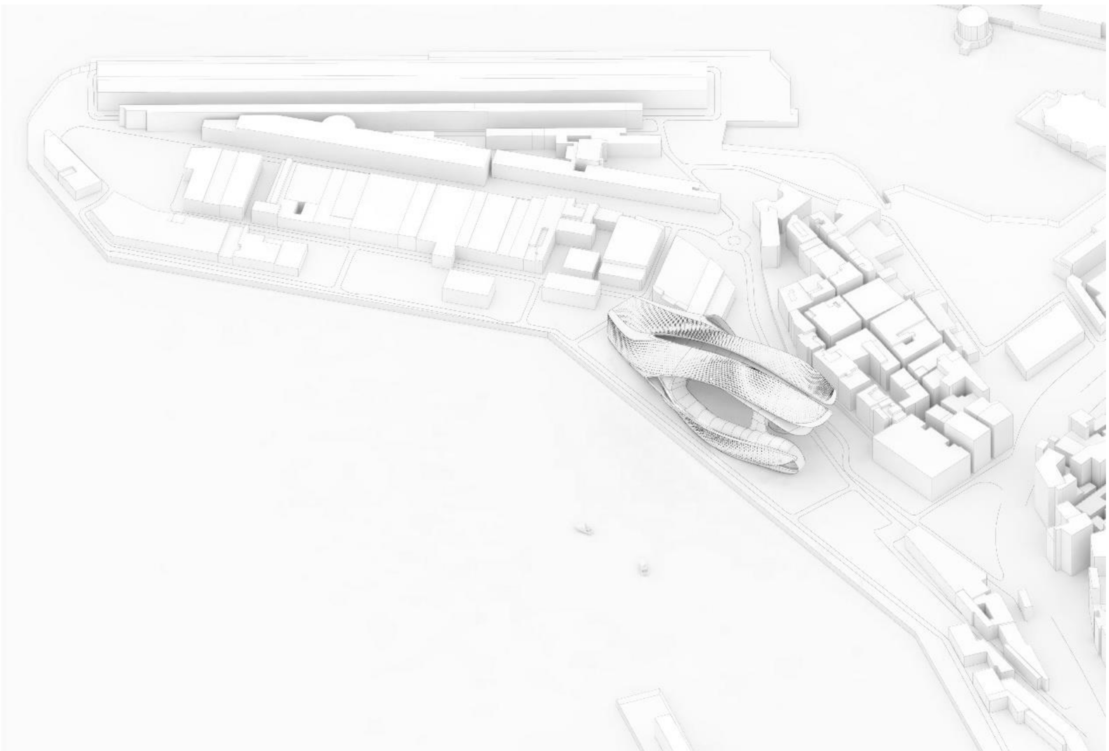


Chart 4-73 Final result of the project design: axonometric drawing

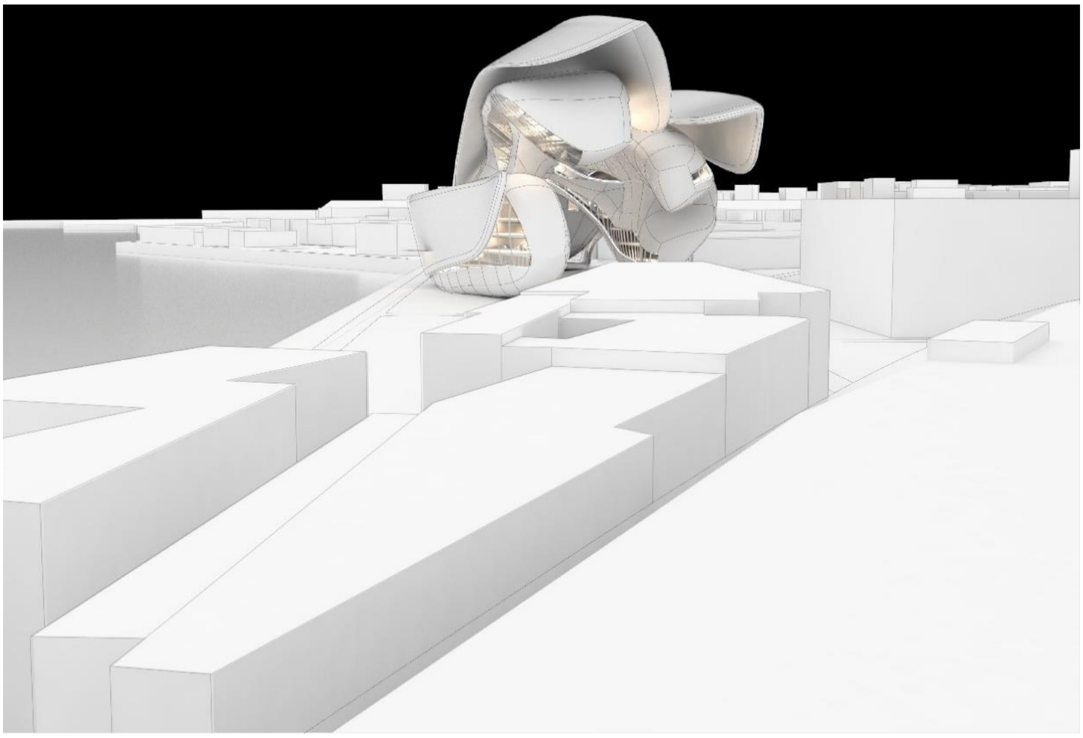


Chart 4-74　Final result of the project design: Angle perspective of elevated road

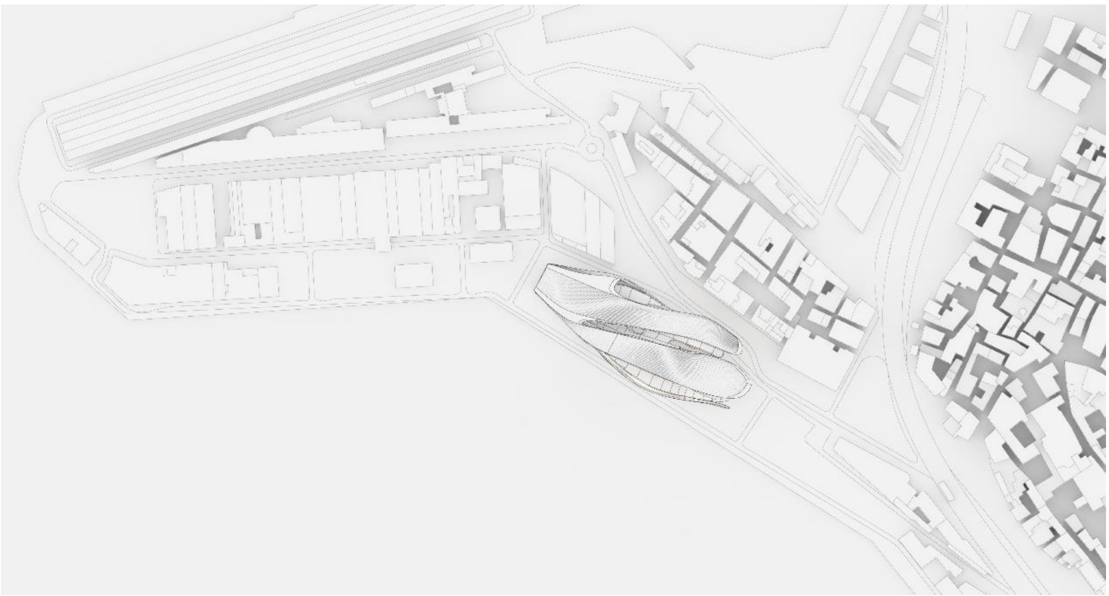


Chart 4-75 Final result of the project design: General layout

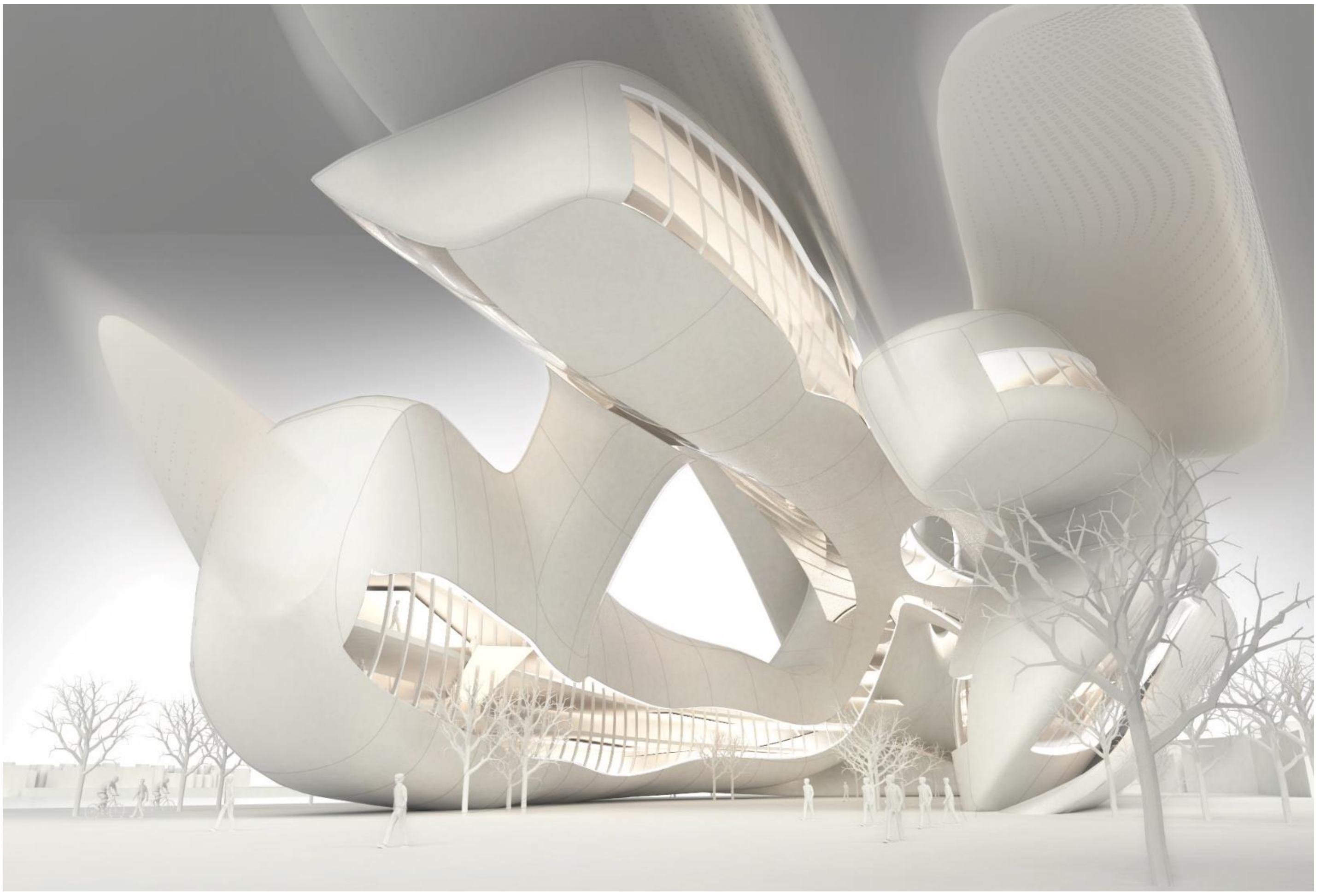


Chart 4-76　Final result of the project design: Square's visual angle perspective

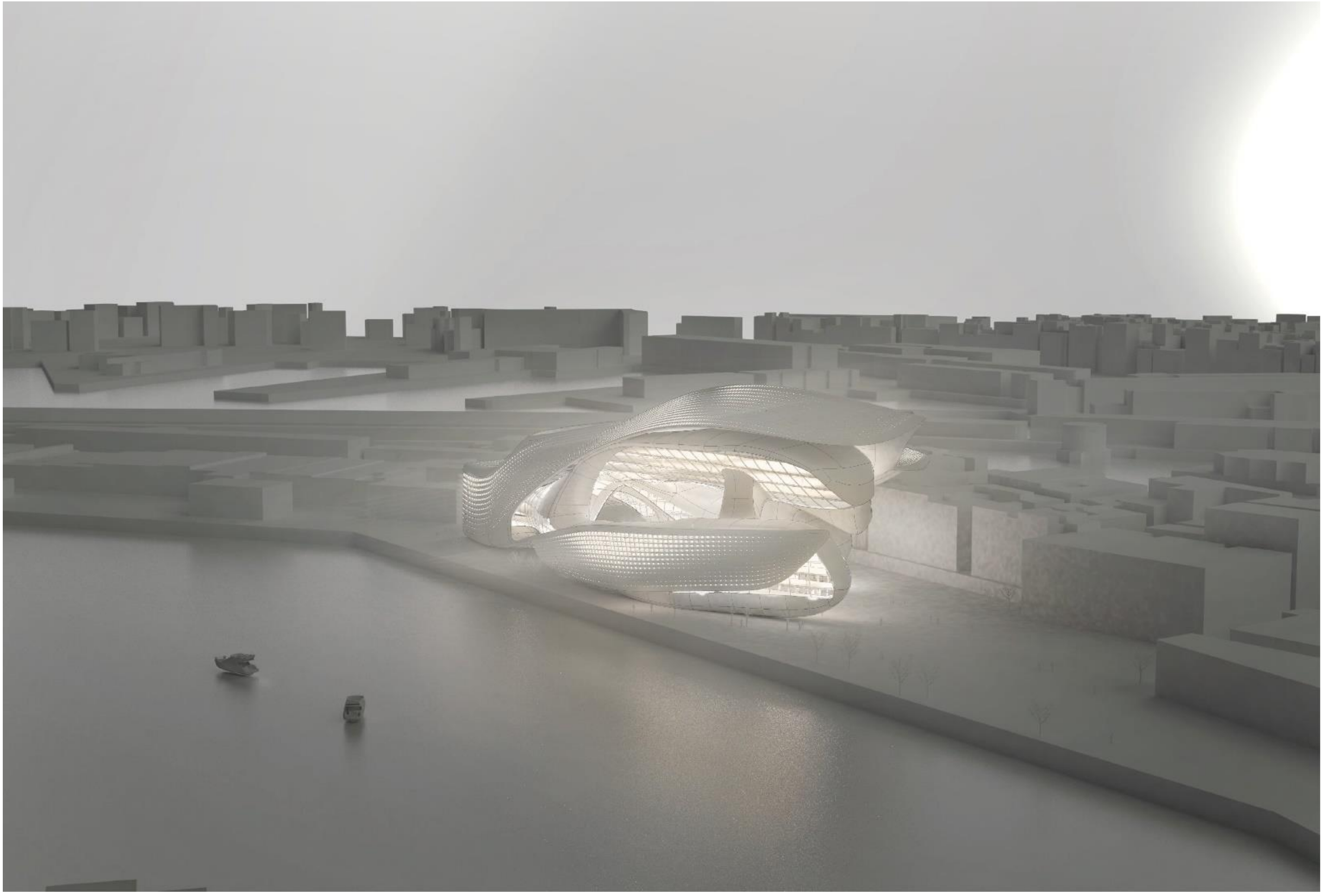


Chart 4-77　Final result of the project design: Sea surface perspective

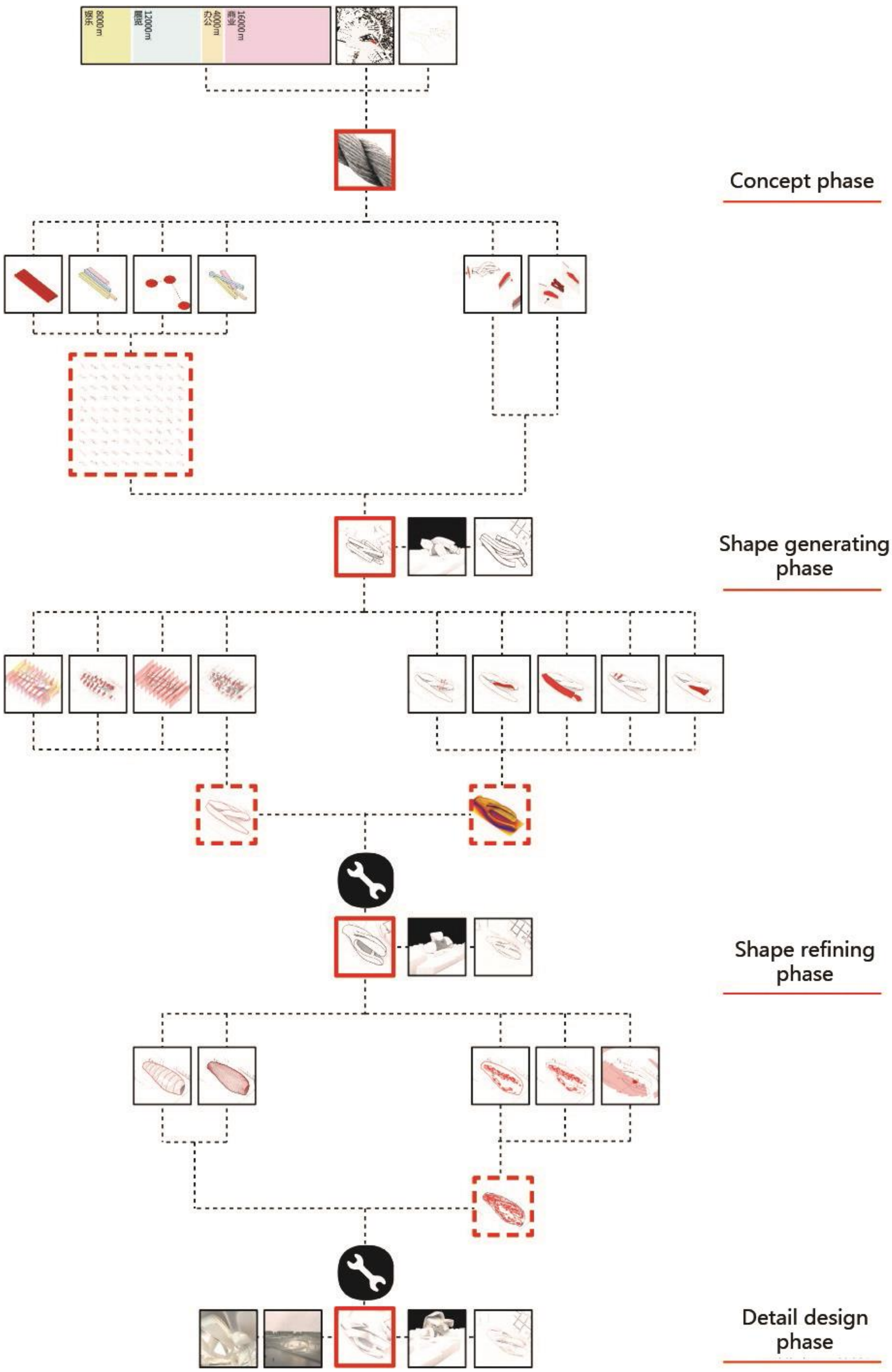

8000㎡
娱乐
12000㎡
展览
4000㎡
办公
16000㎡
商业
Concept phase
Shape generating phase
Shape refining phase
Detail design phase

Chart 4-78 Frame diagram of project design

ChapterV Summary and Prospect

Parametric architectural design based on ecological shaping is one of the new methods springing up in the transition process of informatization in the field of architectural design. Compared with traditional design procedures, because it can be well combined with computer digital technology, it has strong development potential. However, in spite of certain advantages, some limitations are inevitable. In this chapter, while making a summary of the research work, combined with the application of parametric design based on ecological shaping, the author expounds its technological advantages and limitations.

5.1 Work summary

Established in the crossing field of architectural parametrization design method and architectural ecological sustainable strategy, starting from the performance simulation of sunlight and wind environment as well as other environmental factors influencing the architectural usage, and supported by complex scientific theory, architectural shape generation theory and performance driver design theory, the thesis takes environmental shaping and design shaping as the operation path and parametrization design platform and building performance simulation platform as the practice platform. The thesis puts forward the theoretical framework of parametric design based on ecological shaping, explains its working process and verifies the validity of this method in the practical application of the design cases. Through the study and practice of this thesis, it reveals the process where environmental factors are translated into shape driving force, and then it is transformed into self-organizing shape generation system, and meanwhile, the performance driving force is used to carry out the process of optimization solution.

In this research, the outcome of the following three aspects is achieved:

（1） Complex scientific theory, architectural shape generation theory and performance driver design theory are organically integrated, based on which the theory of parametric design based on ecological shaping is put forward.

(2) Based on the parametric design platform, through secondary programming, it realizes the self-organizing generative system and evaluation system of

the architectural shape based on ecological factor, which provides reliable operating path for the theory of parametric design based on ecological shaping.

(3) Architectural environmental simulation technology is combined with architectural shape generation method, and parametric design platform and architectural performance simulation software are used to put forward the theoretical model and flow frame of architectural shape generation method based on environmental factors, which can provide support tools for parametric ecological shaping theory.

(4) Self-organizing generative system of architectural shape is integrated with architectural ecological performance evaluation system to construct a set of complete architectural design method of “generation-evaluation-remodeling.”

(5) Practical design cases is used, the validity of the raised parametric architectural design based on ecological shaping is verified, and its specific operating steps and working procedures are revealed, which provides operating cases for the specific application of this method.

(6) By setting up the theoretical model, constructing the technological platform and verifying the application practice, the parametric design of building based on ecological shaping put forward in this thesis thus becomes a feasible and practical design method. Therefore, it is convenient for popularization and application, which is of both theoretical and practical value.

Parametric architectural design based on ecological shaping is the product of the fusion of parametric design theory and sustainable development theory. Based on the principle of ecological sustainability, the advantage of parametric design platform is exerted. It bears both the directional exploration of the informatization transition of architectural design and the practical application on the interactive law of architecture and environment. The research result achieved in this thesis will strengthen the architectural shape’s responsiveness to environmental factors, help to improve the consideration of environmental factors in the design process and provide more scientific and rational reference for the design practice.

5.2 Follow-up research prospect

Parametric architectural design based on ecological shaping is at the leading edge in the contemporary computer aided design research. With more attention to the architecture's ecological sustainability, continuous increasing demands for the building energy efficiency design and constant progress in environmental simulation technology, this field is certain to achieve more long-range development.

On account of the author's limited ability, there are still some defects in this research. Combined with the application of this research in practical cases, it is summarized as follows, which can be further developed in subsequent research.

(1) The morphological control method needs optimizing. Because the environment's influence on architectural shape is random and complicated, even though the architectural shape generation driven by environmental simulation has distinct and specific generation logic, the shape itself is usually irregular and unmanageable. Apart from the standard of environmental rationality, architecture needs to bear more information such as use function and subjective aesthetic. Therefore, the shape emerging from self-organizing system and driven and optimized by environmental factors needs further adjustment and modification. Aiming at this point, in the subsequent researches, we can also explore how to better combine "environmental rationality" and "shape reasonability".

(2) The applicability of the software platform needs to be expanded. Because of the difference in the data interface and procedural framework among software, there are only a few software platforms accessible to this research method. As a result, in the process of environmental simulation and optimization, it is impossible to have a more accurate simulation and optimization on more environmental factors.

(3) The optimization algorithm needs improving. Through practice, it is found that many optimization algorithms can be realized the user-defined environmental variables and evaluation factors on the parametric programming platform. In this way, it can avoid the resources and time occupied by the data exchange among different platforms so as to realize shape optimization more conveniently. In terms of more effective and advantageous environmental response logic and formula, further accumulation and expansion are needed in practice.

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