Research on Architectural Form Optimization Method Based on Environmental Performance-Driven Design

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Abstract. In the context of contemporary environment and society, the architectural form optimization based on Environmental performance-driven design is a method by using environmental performance data to optimize the architectural form. Its value lies in dealing with the interaction between architecture and environment, and developing architecture with environmental sustainability. This thesis summarizes the similarities and differences between performance-driven form design and traditional bionic form design. The traditional bionic design separates the bionic object from its complex living environment, and its simple imitation tends to fall into the local rather than the global optimum. However, performance-driven design is different from bionic design. It advocates environmental factors as a driving factor rather than a confrontational factor. It is a systematic global optimal method for studying architectural form. This paper puts forward the specific architectural form optimization simulation process based on the performance-driven thought. Taking the multilayer parking building design of the riparian zone on the south bank of Chongqing as an example, the parametric design method is used to obtain architectural optimization form adapted to the environment.

Keywords: Performance-driven design · Form optimization · Environmental adaptability

1 Introduction

With the continuous development of environment, society, economy and technology, the relationship between architecture and environment has been increasingly discussed. The study of the relationship between architecture and environment will inevitably involve environmental adaptability, which comes from the theory of environmental adaptability. This theory was originally derived from the field of biological research at the end of the 19th century, marked by Darwin's theory of natural selection, and was applied to the field of architecture and urban research by the 1850s [1]. The theory is the ideological and theoretical basis of the research in this paper. Buildings should have relative adjustment ability in a specific environment to adapt to the complex changes of the environment. Buildings can be used as a medium to respond to the environment, and it can be presented as a dynamic intelligent collection through interaction with the environment.

The external environmental data of buildings generally have the characteristics of complexity, periodicity, immediacy and combination [2]. Through the design, the environment interacts with the building, combining the environmental performance data with the building. A new mode of thinking is integrated into the Multivariate complex system of architecture, environment and people, making to interact and respond from among the architecture, environment and people (Fig. 1).

2 Performance-Driven Design and Its Advantages

2.1 Performance-Driven Design Theory

Along with the construction, engineering and other industries into the sustainable low-carbon era, the building performance has attracted more and more attention. Simulation technology has quantified the building performance, so architects can incorporate performance analysis into the design workflow. Performance-driven design involves computer-aided optimization techniques that make performance the standard for driving design [3]. Performance simulation technology has been widely used in architectural design for a long time, but in the early stage, it is only used as a design evaluation condition rather than a driving factor of form generation and optimization. In the field of aviation, performance simulation data is used as the design driving force to improve the aerodynamic performance of aircraft, so the performance-driven design method is derived.

Under the action of driving factors and in the process of architectural form shaping, performance-driven design can stimulate the new possibility of building in organization, space, form and performance. Make full use of the natural environment energy to drive architectural form generation and optimization, which can not only respond to the changes of wind environment, light environment, thermal environment, water environment and so on, but also intelligently respond to the external climate conditions of the building based on the energy flow and transfer [4]. The original intention of this study is to start with rational analysis and capture of environmental parameters, and to optimize the overall form of the building under the influence of environmental parameters such as water flow, wind, light and landscape [5].

2.2 Performance-Driven Design Advantages Compared with Bionic Form Design

It is generally believed that the bionic architecture is obtained by using the bionic form design method. Bionic architecture is a kind of architecture which imitates the effective system specialty of some organisms in the aspects of architectural environment, function, form and organizational structure, and it is more in line with the laws of nature and requirements of human nature [6]. In the category of bionic concept, the bionic form design thought such as life-form characteristic bionic, bionic configuration and bionic structure is close to the performance-driven design thought, which have both certain similarities and differences.

From the perspective of similarity, the goals of performance-driven design and bionic form design are to adapt to the laws of nature. Architecture must adapt to the environment to achieve the symbiotic relationship between human and nature. The buildings are

integrated into the circulation system connected with the environment, so as to make more rational use of resources, maximize the use efficiency of energy and materials, reduce the energy consumption of the buildings, make the buildings become a part of the local ecosystem, and make the nature become part of the buildings [6]. Both performance-driven design and bionic form design are architectural form design theory based on the development of environmental adaptability theory.

From the perspective of difference, in the first place, performance-driven design takes performance goals as the driving force, and with the help of computer analysis ability, it can create more diverse form and function solutions under the premise of meeting the comprehensive performance requirements. Select the best scheme through simulation optimization and achieve the optimal solution of multi-objective problem [7]. In the second place, performance-driven design process maximizes the driving effect of performance indicators on the design scheme, it avoids the rework of the design scheme due to the non-compliance of performance indicators and improves the design efficiency. These two advantages promote the application of performance-driven design theory in architectural creation. The bionic form design is more to pursue the goal of the harmony between the architecture and the image of biology. It regards the unity of functional image as the objective basis of harmony and lacks the essential connection [8]. However, performance-driven form design breaks through a single perspective, and it is mainly based on the performance of the system rather than the expression of the function or form, which focuses on performance, that is, function and efficiency [9]. Therefore, the performance-driven form design is a more in-depth development of the bionic form design in dealing with the relationship between architecture and environment.

3 Performance-Driven Architectural Form Optimization Method

3.1 Combined with Parametric Design

The performance-driven parametric design is a design method that combines performance-driven design with the design of “parametric model”. Parametric model is a computer design model, which is based on the geometry. This geometry, itself, contains two fixed features, known as constrained and variable attributes. Parametric design is the form of development based on a set of relations and variables (parameters) [10]. In the parametric model, when a new alternative solution is sought, the parameters will change accordingly. Therefore, it is necessary to adjust the new values of the parameters to respond to such changes, and to define different architectural forms [11].

Under the environment relation, the performance-driven parametric design method combines the parameters of the environmental performance data with the architectural form. This method enables the computer to generate architectural forms based on the building space, structure, materials, and physical environmental parameters such as wind, light, heat and sound, so as to make architectural forms respond to environmental performance [4].

4 Form Optimization Simulation Process Establishment

There is certain discreteness in architectural design so that the design process itself can be simulated by computer. To explore the generation and optimization of architectural form, we need to use performance-driven design thought to find an effective simulation method based on complex models to help complete the design process. The steps of simulation optimization design combined with performance-driven thought are as follows: firstly, traditional design method is adopted for conceptual design; secondly, model is established; thirdly, simulation program is used to analyse one or more related performances; and fourthly, simulation results are analysed and evaluated. On this basis, the design and model are modified repeatedly to find certain rules and the optimal form interval, so as to further drive the detailed design and obtain the target (Fig. 2).

Fig. 1. Diagram of interaction response among architecture, environment and people

Fig. 2. The thought process diagram for performance-driven simulation optimization

Figure 3 shows a block diagram of the performance-driven form optimization simulation process. This paper will only discuss the use of water flow factor as a driving factor in relation to case studies. According to the overall analysis, the preliminary architectural form is designed, and then the parameters of form optimization and the reasonable numerical constraint range are determined. Architects use rhino and grasshopper to build the model, and require that the relevant data of the model must be in the range of parameter numerical constraints, so as to reduce the differences of the optimization results. The simulation process is optimized by the performance simulation platform of Phoenix or RhinoCFD, and the results of stage optimization are obtained. Analyse the data of the results of each stage, and summarize the numerical range of the optimal form that meets the requirements. Combined with other constraints, the optimal form is selected for detailed design, and the final architectural form is obtained.

5 Design Practice

5.1 Project Background

The project is located in the riparian zone of “Egongyan Bridge-Shijiayan” on the south bank of Chongqing (Fig. 4). According to the overall goal of comprehensive control planning of the riparian zone and the natural topographic conditions of the riparian zone, the urban multilayer parking building is designed within the project area of Height

Fig. 3. The performance-driven design generates optimized simulation block diagram

range 186–199 m (Fig. 5). The building site is located in the height range of 180–193 m, which is the urban construction control area of the water level against 5–50-year recurrent floods. The purpose of this study is to demonstrate that the overall form of the design scheme adapts to the site environment. The architectural form should have the flood protection ability in special period. In addition, the building can provide a leisure places for citizens and make it a vibrant riverside area in the city.

5.2 Design Parameters Selection and Numerical Constraint

According to the general design requirements of the project, the architect first needs to do a lot of analysis on the site conditions and functionality. Next, the architect needs to define the basic spatial form of the building, select the corresponding parameters and numerical constraints, so as to ensure that the optimization goal of architectural form meets the design requirements and the rationality of space use.

Considering the influence of boundary line of building and the overall terrain environment on the architectural form, we have chosen the building length-width ratio, building orientation (Fig. 6), building height and number of floors as design parameters. According to the analysis, the numerical constraint of the building length-width ratio is limited to 1.6–3.3, and the architectural forms lower or higher than this range all show certain irrationality. For example, the building space is not suitable for the function or the poor fit with the terrain. The building orientation is limited to 25–30° north-northwest, so as to adapt to the terrain conditions and get a good riverside viewing effect. At the same

Fig. 4. The land area of the riparian zone

Fig. 5. The Scope of project site

time, the building can follow the water flow direction of the Yangtze River, reducing the problems caused by special circumstances. In addition, in order to avoid breaking through the requirements of the optimal design scheme, we also limit the total building area and the building footprint as parameters. The specific parameter numerical range are shown in Table 1.

Table 1. The constraint conditions on parameter range of architectural form optimization design

	Parameter name	Numerical constraints	Unit
1	Building length-width ratio	1.6–3.3	—
2	Building orientation	North-northwest 25–30	°
3	Building height	13.5–16.5	m
4	Number of floors	3	—
5	Total building area	13500–16500	m ²
6	Building footprint	4500–6000	m ²

5.3 Setting Simulation Parameters

5.3.1 Water Velocity

The engineering reach is located in the upper reaches of the confluence area of the Yangtze River and Jialing River, and is called the Dumb Cave reach. The flood fluctuation of the two rivers will affect the water level in this reach. By analysing the historical data of Zhutuo hydrological station, Cuntan hydrograph station, Beibei hydrograph station and Egongyan stage gauging station, the water velocity of simulation is 2.37 m/s.

5.3.2 Water Flow Direction

According to the water flow direction of the whole Yangtze River, in the engineering reach and from the upstream to the downstream, the water flow direction of simulation is north-northwest direction (considering a single direction temporarily to facilitate calculation and simulation).

5.3.3 Water Level Height

The numerical values of water level height related to the building are shown in Table 2. The water level height of simulation is the water level against 5-year recurrent floods—185.6 m.

Table 2. The characteristic water level height value associated with the building

	Water level name	Water level height/m	Relative building height/m
1	Water level against 50-year recurrent floods	191.7	11.7
2	Water level against 5-year recurrent floods	185.6	5.6
3	General highest water level	173.0	−7
4	General lowest water level	164.5	−15.5

Note: Yellow Sea Elevation

5.4 Form Optimization Process Diagram

The whole simulation process of form optimization is adjusted in multiple stages. The initial conceptual design was the traditional block shape. But through the Phoenix water flow simulation analysis, the concave space of the building will be affected by the severe impact of the water flow, which is not conducive to the overall structural performance. Therefore, the architectural form is pushed outwards to gradually weaken the boundary of the rectangular block, so as to adopt a soft curve form. Finally, we get the spindle shape with better performance. And on this basis, we find the optimal performance range by changing the building length-width ratio and shape for many times. Figure 7 shows the evolution process of architectural form in simulation and optimization. Figure 8 and Fig. 9 respectively show the pressure value diagram and the velocity value diagram of the water level against 5-year recurrent floods in 18 phases schemes.

5.5 Result Analysis

The shape coefficient of building (the ratio of the external surface area of the building in contact with the outdoor atmosphere to its volume) is chosen to describe the architectural form characteristics. According to research, the smaller the external surface area

Fig. 6. Diagram for determination of building aspect ratio and building orientation

Fig. 7. Optimization of architectural form evolution

Fig. 8. The pressure value diagram of simulation process

allocated on the unit building volume, the smaller the impact of water flow on architectural form in the special period, that is, the more conducive to the stability of the overall structural performance of the building. We extract the corresponding maximum and minimum pressure values (velocity values) from each stage of simulation and average them. And then, combined with the shape coefficient of building, the average pressure value and the average velocity value, we find out the relationship among them and get the optimal form numerical range. Table 3 shows the relevant data values of the above 18 simulation phases. The data values of every phase are within the effective range of the design parameters.

Fig. 9. The velocity value diagram of simulation process

Figure 10 shows the line chart of the relationship among the average pressure value, average velocity value and the shape coefficient of every simulation phase (the numerical variation range of the shape coefficient is too small, so we expand the numerical value by 10 times in order to clearly present the curve variation rule). In the simulation of the architectural form No. 1 to No. 13, the average pressure value, average velocity value and the shape coefficient have a general trend of gradually decreasing, which indicates that the effect of water pressure on them decreases with the change of form; the shape coefficient of the architectural form No. 14 to No. 18 tends to a relatively stable value, but the corresponding average pressure value and velocity value show an upward trend. To sum up, the architectural form No. 13 and No. 14 are relatively better. By designing them in detail and again using Phoenix simulation, the building is least affected by the water level against 5-year and 50-year recurrent floods, which is more stable, safe, beautiful and sustainable than other design forms.

Table 3. The relevant data values of every phase simulation

	Total building area /m ²	Building footprint /m ²	Building length /m	Building width /m	Building length-width ratio	Building height /m	Maximum pressure /pa	Average pressure /pa	Maximum velocity m/s	Average velocity m/s	External surface area /m ²	Volume /m ³	Shape coefficient
1	15364.21	5121.41	138.48	55.29	2.50	13.50	2.80	5.76	3.86	1.94	16752.72	69138.96	0.2423
2	15638.91	5212.97	140.05	66.65	2.10	13.50	2.59	4.62	3.56	1.79	17066.57	70375.05	0.2425
3	14785.31	5026.07	140.05	62.04	2.26	15.80	3.00	3.65	3.44	1.72	14760.49	61889.81	0.2385
4	14584.16	5614.31	145.11	58.95	2.46	16.50	2.81	3.35	3.38	1.69	15286.39	60671.71	0.2519
5	16146.12	5939.09	150.31	65.85	2.28	15.20	2.53	4.49	3.82	1.92	16350.24	68579.62	0.2384
6	16010.76	5003.09	144.73	67.21	2.15	15.20	2.79	3.85	3.39	1.71	15234.88	70464.66	0.2162
7	16253.28	5006.14	150.09	63.44	2.37	15.20	2.52	3.59	3.29	1.65	15403.99	73286.18	0.2102
8	15424.21	4784.01	149.24	60.54	2.47	15.20	2.63	3.33	3.09	1.55	15464.31	73301.31	0.2109
9	16336.52	5446.21	150.04	60.34	2.47	16.50	2.16	3.71	3.54	1.79	15452.59	71568.99	0.2087
10	15416.87	4632.56	150.21	53.13	2.83	15.20	2.02	2.85	3.09	1.59	15747.32	75449.96	0.2005
11	15270.15	4574.28	157.79	48.61	3.25	15.20	1.83	3.42	3.08	1.60	13930.61	68302.12	0.2039
12	15124.29	4528.12	154.69	48.37	3.19	15.20	2.43	3.00	3.15	1.59	13688.67	67853.43	0.2017
13	15675.26	4757.42	155.57	52.79	2.95	15.30	1.93	2.23	3.09	1.59	13973.08	69873.07	0.2001
14	15326.79	4643.76	164.39	52.77	3.12	15.30	1.82	2.50	3.11	1.64	13872.24	68051.48	0.2038
15	15348.49	4670.62	169.73	54.21	3.13	15.30	2.05	2.66	3.09	1.65	13997.35	67943.66	0.2060
16	15744.41	4665.43	142.27	67.46	2.11	15.30	2.10	2.69	3.15	1.64	13950.96	71148.68	0.1961
17	14954.44	4531.41	124.44	74.63	1.67	15.30	2.08	2.95	3.27	1.68	13050.84	66743.06	0.1955
18	15429.91	4515.17	128.60	69.83	1.84	15.30	2.27	3.02	3.23	1.62	13455.92	69264.66	0.1943

Fig. 10. The broken line diagram of relationship among mean pressure value, mean velocity value and shape coefficient

Fig. 11. A rendering of the final building scheme

6 Conclusion

In the context of contemporary environment and society, to develop sustainable energy and to protect environmental ecosystem urgently need to develop the new architectural design strategy.

Only passively seeking design inspiration from nature, and the bionic design of existing mode can no longer meet the demand of sustainable building development. Under the influence of various complex environmental factors, it is necessary to apply the performance-driven design thought to find the optimal value of the architectural form optimization design that responds to the environment. Performance-driven design gives full play to the advantages of digital technology, making the selection of its results more proactive and avoiding being limited to the design of local optimization. In short, the performance-driven design method can truly combine design with nature to drive the development of energy-efficient buildings and sustainable buildings [12].

In addition, the architectural design of riverside area is a research subject to be further developed and utilized. There are many uncontrollable environmental factors in the riverside area, which will affect the architectural form, the construction process, Use process and maintenance process of building. In the design process, it advocates environmental factors as the driving factors rather than the confrontational factors, so as to improve the energy efficiency of the building environment. The design practice explores the optimization strategy of architectural form in riverside area influenced by the performance-driven design thought. The results of simulation and optimization show that the architectural form is not only satisfied with other design conditions, but also affected least by the specific water flow factors of this area. The final optimized architectural form combines the urban space, embankment features and surrounding landscape to form a building of the modern design feature (Fig. 11). More importantly, this provides strategic guidance for further development of programs, that can be modelled, simulated, evaluated, optimized and generated simultaneously.

At present, we are gradually realizing the transformation from computer-aided design to computer-decided design. The latter will focus more on the global optimal study of architectural design problems at the level of the self-organization generation and adaptive optimization. This will be a new exploration of architectural design thinking, methods and technical tools in the context of artificial intelligence technology. It is bound to

integrate more vigorous vitality into the sustainable design concept of environmental performance.

References

1. Lynch, K.: Environmental Adaptability. *J. Am. Inst. Plan.* **24**(1), 16–24 (1958)
2. Li, L., Ye, X., Wang, Y.: Environmental intelligent architecture. *Time Archit.* (2018)
3. Shi, X.: Performance-based and performance-driven architectural design and optimization. *Front. Archit. Civ. Eng. China* **004**(004), 512–518 (2010)
4. Li, L., Tao, S.: Evolution of green building and energy agenda of architecture. *South Archit.* **03**, 27–31 (2016)
5. Wu, J., Li, L., Wang, J.: Environmental responsive construction; Qingdao Linghai Hotel. *Time Archit.* (04), 142–147 (2016)
6. Wan, K.: New discussion about architectural bionic. *Huazhong Archit.* **03**, 28–31 (2005)
7. Sun, C., Han, Y., Zhuang, D.: A study of dynamic building information modelling techniques based on performance-driven thought. *Archit. J.* **08**, 68–71 (2017)
8. Lv, F.: Toward the 21st century – the past and future of architectural bionics. *Archit. J.* **06**, 14–17 (1995)
9. Yang, T.: The preliminary discussion on the generative and performative design. *Archit. Pract.* (2013)
10. Lotfabadi, P., Alibaba, H.Z., Arfaei, A.: Sustainability; as a combination of parametric patterns and bionic strategies. *Renew. Sustain. Energy Rev.* **57**(May), 1337–1346 (2016)
11. Hernandez, C.: Thinking parametric design: introducing parametric Gaudi. *Des. Stud.* **27**, 309–324 (2006)
12. Lin, Y., Yao, J., Zheng, J., Yuan, F.: Research on the building morphology generation method based on the wind tunnel visualization of environmental performance. *South Archit.* **02**, 24–29 (2018)

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