Exploring the Application of Parametric Design in Architectural Optimization

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Abstract. The digital era, urbanization, and enhanced public aesthetics have profoundly impacted the design industry, necessitating advanced skills for contemporary designers. This study explores the application of parametric technology in cultural and art museum architecture. By employing parametric tools and mathematical logic, the research highlights the advantages of visualization in architectural optimization, fostering industry advancement with innovative design concepts.

Keywords: Parametric, Visualization, Optimization.

1 Introduction

Cultural differences lead to varied design philosophies. In China, the high intensity and efficiency of design practices often leave little time for designers to contemplate the impacts of technological innovation on design methods[1]. Much of their time is consumed by repetitive, tedious tasks, with little opportunity for exploration and research. However, technological advancements can significantly enhance work efficiency and reduce labor-intensive design work focused on manual efforts[2].

Domestically, conservative attitudes towards design overlook the impact of the digital age on the design industry. There is an over-reliance on the subjective designs of the designers rather than leveraging computer-aided design tools that could provide substantial support. Professor Xu Weiguo from Tsinghua University defines parametric design as "a process where changing the values of parameters alters a design element's properties, or uses parameters to characterize a design element's nature." He suggests that the parametric design process involves three phases: first, the data processing of design elements; second, establishing parametric logical relationships; and third, using computer technology to build parametric models[3].

The rapid evolution of the internet age drives crucial technological advancements, pivotal for revolutionizing design. Parametric design, born in the digital era, marks a fundamental shift in design ideology. This study aims to cultivate a parametric design mindset, utilizing parametric tools and mathematical logic for architectural analysis, and drawing on parametric theory for form creation. Its goal is to scientifically and

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precisely analyze influential factors and innovate in optimizing form generation. Through summarizing algorithms and mathematical logic on platforms like Rhino and Grasshopper, simulating form generation via software, and enhancing parametric design thinking, it seeks to transcend traditional design constraints.

2 Research Background and Expected Research Results

2.1 Research Background

The selection of a design site requires consideration of the city's cultural founda-tion and urban architectural texture, as well as natural climate and cultural character-istics. This study selects the Luohu District Cultural and Art Museum in Shenzhen as the focus of design for two main reasons: firstly, the design is based on the compe-tition brief issued by the Luohu District, ensuring that the design objectively meets specific functional needs and is not merely speculative; secondly, Shenzhen is a city at the forefront of reform and opening up, where new design concepts and forms can integrate seamlessly due to its strong inclusiveness, allowing the latest design ideas to flourish.

The Luohu District Cultural and Art Museum site is located on Liantang Street, a residential area in Luohu known as the district's "back garden" due to its lush environment and high greening rate. The site, covering 4521.7 square meters, is situated between Wutong Mountain and botanical gardens, with cultural landmarks like temples and auditoriums nearby. Given the hot and rainy climate of the south, the design will utilize open, flowing, and expansive Lingnan architectural spaces, with careful attention to views of Wutong Mountain and the site's significance as a key traffic junction.

3 Application Research of Parametric Design in the Field of Building Optimization

3.1 Elevation Data Acquisition and Terrain Creation

Utilizing Rhino and Grasshopper, precise terrain data for the Luohu District Cultural and Art Museum in Shenzhen were acquired and modeled. Terrain elevation data were stored on a parametric platform, enhancing management and modification efficiency. Geographic spatial data from the internet, specifically within longitude 114.165° to 114.190° and latitude 22.554° to 22.568°, were obtained. DEM elevation data were processed in Global Mapper to produce a shapefile vector file containing contour lines and elevation data, which were extracted using ArcMap. Grasshopper then utilized these data for logical calculations to generate the terrain.

3.2 Parametric Generation of Related Architectural Features

Initially, building elevation data are obtained from BIGEMAP in Shapefile format, which includes building outlines and height information. These files are then processed in Arcmap to produce building height data tables and the locations of specific points. Finally, this data is integrated into the parametric platform for complete building generation. Grasshopper's node-based programming accurately matches data and quickly completes building generation. Its programming setup allows easy site data swapping, significantly facilitating subsequent design processes. Generating information on surrounding buildings is crucial for analyzing the relationship between the museum and its environmental context, and it forms an indispensable part of the architectural design analysis for the museum.

3.3 Parametric Generation of Other Site Information

In addition to buildings and terrain, roads and rivers and other relevant features must also be considered in site design. Analyzing traffic relationships is an essential part of site design. The generation of roads and rivers differs slightly from that of terrain and buildings, with data sourced from the BBBIKE map platform. Similar to previous methods, relevant element Shapefile files are obtained and then analyzed and extracted using parametric software platforms.

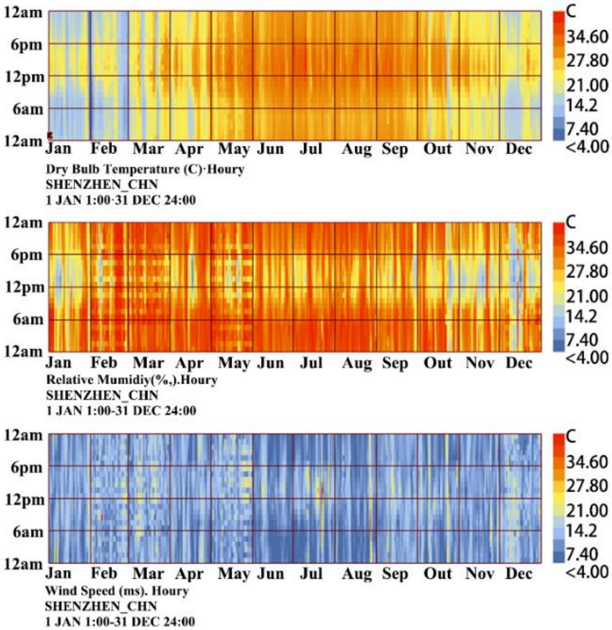

Fig. 1. Annual Temperature Chart, Annual Humidity Chart, Annual Wind Speed Chart

3.4 Parametric Analysis of the Design Site

For sunlight analysis, key software includes TIANZHENG, Ecotect, and the Ladybug and Sunflower plugins on parametric platforms. This paper selects the Ladybug plugin for two reasons: its precise geographic pinpointing and its diverse representation forms that clarify sunlight coverage and duration[4].

With the parametric model of the Luohu District Cultural and Art Museum site generated, sunlight analysis is performed directly on Grasshopper. Grasshopper simulates solar exposure based on date and geographic coordinates, producing accurate solar exposure maps. The meteorological data for Shenzhen and the site's location were obtained via EPWMAP, as shown in Fig 1 and 2, with analyses conducted on the winter and summer solstices.

The analysis shows no tall buildings causing shading, ensuring ample sunlight year-round. The design process must consider sunlight exposure and the building's radiative effects on its surroundings. Vegetation around the building should be heat-tolerant, and building materials should be heat-resistant.

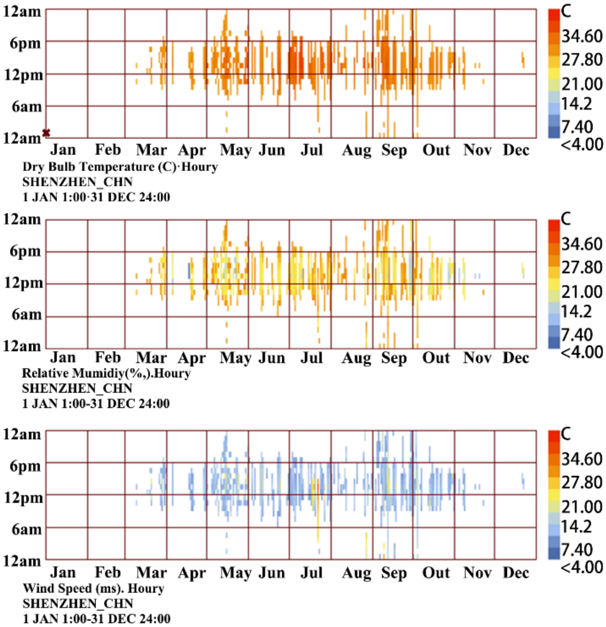

Fig. 2. Chart of Months with Adjustable Natural Ventilation

3.5 Meteorological Data Analysis

Traditionally, the investigation of a site's natural environment relies on the designer's judgment or long-term measurements with instruments. Although instrument measurements are accurate, they are time-consuming and costly. The collection of big data and parametric generation allows for the relatively accurate representation of local meteorological conditions, assisting in the design process.

Further exploration into parametric-assisted design analysis reveals that for non-natural elements such as traffic, population, and crowd dynamics, visualization analyses can be effectively conducted using parametric techniques. However, this requires extensive data collection to accurately analyze the impact of these non-natural elements on architecture. Parametric technology can simulate traffic flows and pedestrian movement patterns, providing valuable insights for design. Nevertheless, data collection presents certain challenges. The acquisition of relevant information often involves confidentiality issues and the impact of many uncertain factors. Key information might need to be requested through government portals, hence it is not extensively discussed here.

3.6 Exploration of Parametric Layout Optimization for Building Interior Spaces

The design of floor plans entails rationalizing layouts by considering various factors for optimal results. Advances in computing power enable parametric technology platforms to internalize constraints and employ optimization algorithms to generate satisfactory plans[5]. The Magnetizing Floor Plan Generator plugin in Grasshopper aids designers in addressing cognitive challenges. However, parametric assistance in floor plan design has limitations, especially in larger spaces with numerous elements like bathrooms, staircases, and elevator shafts, where spatial constraints pose challenges. Additionally, parametric tools struggle with creating or selecting spaces with curved surfaces or corners, often resulting in impractical structures.

In designing the floor plan of the Luohu District Cultural and Art Museum, the spatial arrangement aligns with design requirements. Parametric generation facilitates the creation of smaller spaces and visitor routes, particularly for orderly layouts like exhibition areas. While the overall floor plan requires holistic consideration, sub-spaces are optimized using parametric technology. Exploration of the exhibition space involves defining boundaries, determining sizes, setting entrance positions, and conducting optimization calculations for walkways. The exhibition hall layout comprises one central and three auxiliary areas, with continuous optimization until a plan is selected. Parametric floor plan generation offers designers reference ideas, yet final selection and optimization demand further refinement.

3.7 Digital Performance Evaluation of Building Interior Spaces

Evaluating the natural lighting performance of interior spaces optimizes window size and placement. Using the Honeybee plugin in Grasshopper, daylight parameters are input to calculate indoor natural light illuminance at 10 AM on June 22. Effective indoor daylight illuminance ranges from 100 to 2000 lux, avoiding glare and overly dark conditions.

A scientific evaluation of the natural lighting in the Luohu District Cultural and Art Museum is crucial for the detailed design phase, informing the floor plan layout and window placement. The analysis reveals how the building's structure impacts indoor lighting and allows dynamic adjustment of illuminance through computer analysis, considering material properties and window openings. This enhances the logical lay-out of interior spaces, achieving more effective designs.

4 Conclusion

Research indicates that parametric technology significantly enhances data acquisition and design element analysis. Accurate data ensure precise analysis and model integrity, transforming traditional complex processes in terrain creation and architectural modeling, thereby increasing design efficiency. However, parametric technology is primarily employed in the research and analysis phase, with limited use in the initial "meta-design" stage. As the design progresses, meta-design elements are continuously optimized using parametric technology based on performance evaluations, refining architectural and spatial standards. During construction, integrating parametric technology with Building Information Modeling (BIM) effectively addresses construction issues. Despite its advantages, parametric design does not permeate the entire design process and requires multidisciplinary collaboration to fully realize design plans.

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