Digital Aided Façade Design Introduced in a Traditional Design Workflow

An experience from one large-scale museum design and construction practice

Chenlong Ma¹, Shuyan Zhu² and Ke Xiang³
¹,³ School of Architecture, South China University of Technology
¹ miraclema999@gmail.com ³kee53@126.com
² Architectural design and research institute of SCUT
² 124464315@qq.com

Abstract. This paper discusses the opportunities and barriers of adopting parametric tools in discrete elements of the design development documentation processes in parallel with more traditional 2D computer aided architectural design (CAAD). We believe it is a more reasonable way for small to middle sized design companies in China, to introduce parametric design method into the design and construction process, especially when there being a long way from traditional CAAD approach to an all-BIM future in China.

Keywords. Parametric tools; collaborative design; façade design.

1. Introduction

While advances are occurring in the field of innovative architectural design exploring the increasingly complex terrain of parametric design theory, there has not yet been an explicit effort to introduce advanced parametric tools to the process of constructing complex non-innovative form buildings. The nature of large complex buildings requires high levels of collaboration and specialized skills in their erection, and parametric models can considerably reduce the time required and help improve communication between multi-disciplinary teams. In this paper, the National South China Sea Museum is used to illustrate the ways in which these benefits manifest in built work. This paper is written in light of the completed building and provides a description of the design process of the façade design and the parametric way applied.

The National South China Sea Museum is located in Qionghai, Hainan province, it is a key exhibition location of the history and culture of the South China Sea, and it also serves to promote exchanges and cooperation among countries along the maritime Silk Road. The stretching and flowing shape of the museum comes from traditional elements of South China Sea-the figures of sailboats, sea waves, traditional boat houses and fishing net (Figure 1). Since this modest curved shape is to some extent non-innovative as compared with the architectural examples of Zaha Hadid or MAD, a more traditional design workflow was adopted.
The detailed design of the curved shaped roof and cylindrical façade required more effort compared with buildings of quadrature axes, whilst the demand that the museum be partly open to the public before the 2017 Boao Forum for Asia necessitated a short construction period and short design period. The design team introduced a number of parametric tools in the detailed design process for the façade. This paper describes the way in which the project architects were able to handle the detailed design of the façade using a digital aided approach in combination with the typical traditional AutoCAD workflow for a large-scale museum to help shorten the design period.

Figure 1. Sketch of the National South China Sea Museum.

2. Information workflow

Owing to the short design period and the absence of BIM teams skilled in using Revit, ArchiCAD and similar software to handle the whole construction process (this will be discussed in part 5), whilst Rhinoceros3D and Grasshopper were widely used among the design team, the Rhinoceros3D platform was chosen to aid in the detailed façade design. Since the base model of the shape in bidding period was designed using Rhinoceros3D, to ensure the continuity of the whole detail design process the software remained in use throughout it. There are several discussed plugins for algorithm optimization (Jason and El Sheikh 2011; Roudsari and Pak 2013), while environmental simulation, the presenting of models and the interface are easy, especially for architectural design and cooperation.

Right after the bidding period, a simplified model was built by architects on the Rhinoceros3D platform setting out geometry. This model focused on setting out axes grid and outlines for the building façade. In this project, all the elements were treated as consisting of three independent groups: the big roof connecting with structural columns, the façade, and the inner walls forming the complex inner spaces. Referring to the set-out geometry, the three groups were designed separately before being merged into one final building. The detailed roof design and the support structures below were completed by several other independent teams. BIM software such as Tekla Structures were used to cope with the subsequent fabrication process. While the façade design was done by the design team within Rhinoceros3D platform, to ensure perfection of the final visual effect. As to the inner walls, their 2D floor plan drawings were executed within the AutoCAD platform, to ensure deeper cooperation with designers from other departments such as structure, water supply and drainage, HVAC, electric and
sustainability—which is the typical traditional design approach, but at this specific stage it was a very reliable solution (Figure 2).

As to the output of drawings, an information workflow was designed to implant a parallel parametric design process in the traditional one, undertaking the drawing of sections, elevations and the outlines of façade on floor plans. In a typical traditional design process, all the drawings including floor plans, sections, elevations and design details are drawn within the AutoCAD platform; however, most of time, the different types of drawings are developed separately, which causes massive amounts of time to be expended on checking for correctness, especially when designing a building in a nonorthogonal system. However, in Grasshopper, scripts of several packaged commands could be built, allowing surface projection, slicing, recombination and so on to be automated in the generation of elevations, sections and shelter plates. These drawings only required little in the way of subsequent revision by designers before plotting. The main drawing of floor plans was implemented within traditional AutoCAD software, with the outline of the façade left as control lines, while the detailed design of the whole façade was all completed in Rhinoceros3D using these imported control lines. Designers used the imported plans in Rhinoceros3D to check the interior space design using 3D models and automatically exported sections at predetermined locations. The detailed outlines and dimensions of the whole façade were then generated in Rhinoceros3D and exported into the ‘.dwg’ format and paste-in-place as a block into each plan level.

3. Choice of module dimension

There were two kinds of façade types—glass curtain wall and tall windows, arrayed on walls that were sheltered by customized perforated plates. The two types are all cylindrical ones. In the traditional section of the plan design process, the curved walls were divided into series of continuous arcs, to help the traditional layout survey. To achieve the fluid shape and the atmosphere of inner space, complex axis
systems were used. The structural axis of the building, the profile of façade and the inner walls were not designed in the same axis systems causing correspondence of the continuous outer façade and the complex inner wall to be impossible.

As the structural axis and the façade axis did not share the same center for their circles, this meant that the curtain wall of the east façade facing the seaside was not evenly divided by structural axis, and the modules were required to have different dimensions, which changed incrementally (Figure 3). From intuition, because the east lobby of the building was a very long space running through the whole structure, if incremental dimensioning was not maintained, users would notice the compromise through the inner view of the long lobby. There were three different alternative choices: first was maintaining the incremental dimension of the whole; second was dividing three modules equally at every other axis; the last was using even less dimensions and using a much larger tolerance. From the visualization on the Rhinoceros3D platform, the decision was made to choose the second approach as the difference was inconspicuous from all viewing angles.

Figure 3. Plan of the building: arc-shaped outlines not sharing the same center; Red: curtain wall; Blue: tall windows arrayed on walls that sheltered by perforated plates.

The tall windows system needed to have the same dimensions to help ensure a shorter production time for the time-consuming manufacture of the perforated plates and to ensure a uniform façade, but the distance between the inner walls was non-standard being complex functions and thus not all fitting the same dimensions. The tall windows system was thus naturally divided into disconnected parts and
assigned to different groups. Inside each group, unique module dimensions were used that balanced the outer appearance and the inner division. In this context, under the precondition that the inner walls all met the outer wall, the smaller number of dimensions (that is more groups sharing the same dimension) was selected as the more optimal solution (Figure 4).

Choosing the number of dimensions groups and the dimensions of each groups would normally be ascertained in the traditional design process through trial and error, which would be time consuming. However, because of the use of a parametric platform, the mature GA tools in Grasshopper were used to calculate the most appropriate length for each dimension group in just minutes. This way, mismatch between windows and inner walls was successfully avoided and the most optimal choice guaranteed. Through the Rhinoceros3D platform, designers were also able to visually decide the tolerance of the dimensions in real-time.

Figure 4. The GA tools to decide the number of plate groups and the exact dimension.

4. Optimize of sunshade plates

Customized perforated plates with three different sizes of triangle shaped holes were used to design three patterns and form an impression of waves on the west façade. Architects usually want to link subjective artistic designs with some objective reason. In this project, the designers wanted to link the picture on the façade with the consideration of daylight requirements. So, the testing of the efficiency of perforated plate using daylight simulation was used to help designers decide the size of the holes and the boundaries of the three patterns. According to the thought of architects, the upper area of the plates was placed right in the shadow of big roof, there should be bigger holes to let more sunshine in, vice versa (Figure 5).

Radiance and several add-ons on the Grasshopper platform were introduced to test and modify the detailed design. Simulations of external lighting in a CIE overcast sky were used to evaluate the difference in hole size impact on the lighting of the inner space. The tools used were the ladybug & honeybee plugins which linked Grasshopper to Radiance. Because of the large number of polygons, radiance glass material was used as replacement for plate. (Mainini et al. 2014) The perforation percentage of the different patterns were calculated, and then the data
was translated into the transmittance of the radiance glass material. Based on the simulation, without plates or with plates of the same perforation percentage, the upper floors would receive low sunlight compared with the lower floor. However, through adjusting the designed pattern, the difference among the upper and lower floors was reduced (Figure 6).

Figure 5. The sunshade plate design. Up: the detail of panels. Down: the overall distribution of panels on the façade forms an impression of waves.

Figure 6. Daylight simulation- The use of plates with 3 different size of holes leads to even sunlight environment of different levels compared with that of the uniform ones.

A photometric simulation was also ran using Thea for rhino. The before and after light environment of the office spaces could therefore be seen right on the screen. Through simulation of the inner light environment, architects’ intuitive design gained quantitative support (Figure 7). The final choice of hole dimensions was decided based on the considerations of daylight consumption, indoor light environment and structural strength requirement of the plate obtained from the façade consultant (Figure 8).

As there may be considerable construction errors due to the lack of advanced
construction techniques in Qionghai, collision avoidance was considered. The sunshade plates overhang by a considerable distance, making it easy for them to overlap with the large curved but slightly lower roof. The outermost point of every plate was also extruded, the vertical projected points on the roof’s underside were used as the reference points, and the level chosen as a fixed distance under these points, as the highest boundary of every plate. The chosen distance was made to, on one hand, avoid the collision and, on the other hand, cover up uneven distances in the final construction of the plate and roof.

![Figure 7](image1.png)  
Figure 7. The photometric analysis and unbiased render of inner space. Through the use of sunshade plates, glare has been significantly reduced.

![Figure 8](image2.png)  
Figure 8. Photos of sunshade plates on the west façade.

5. Conclusion - the transitory stage of traditional CAAD

At the current transitory stage from traditional CAAD approach to an all BIM future, even though the development and construction activities of China continue to overshadow those of other countries, much day to day work is conducted at low skill and basic technology levels (Herr and Fischer 2017). Besides some
high-profile projects conducted by large design firms (Wang and Shen 2015; He et al. 2017), most smaller design companies do not yet adopt BIM-supported workflows in their projects. Because of the professional separation and tight time constraints in China, most construction processes rely on 2D drawings to cope with the demand for high-speed design and construction, especially as integrated BIM workflows have not been well established (Zhang et al. 2013; Luo et al. 2015 Ding et al. 2015). Parametric tools are usually employed in the early design process; however, this paper believes that the use of these tools during construction process is a reasonable choice for most design teams in China. The series of instances above illustrate how the parametric approach was implemented in the design and construction of the façade of National South China Sea Museum. This design process employed the popular Rhinoceros3D software as the base platform, and apart from the traditional drawing process of floor plans, a digital aided design process was used to cope with the detailed design of the façade and a number of repeatable design drawings.

The use of a customized parametric approach in the façade design had many advantages. Through visualization and simulation, architects were able to better understand each design step from a more digital perspective. Since Rhinoceros3D software and add-ons are widely used by many architects in the early design period, it will cost relatively little compared with the typical BIM process which requires designers to learn a new software, and architects in this project were able to use Rhinoceros3D across the whole process. Compared with the traditional design and construction process, this approach not only shortened the time taken by utilizing customized automation tools, through the use of add-ons like GA tools, sunlight simulation tools, finite element analysis software, energy consumption simulation tools, customized scripts, architects can optimize building designs in a more scientific way. It can therefore be considered to be demonstrated that such customized parametric approach allows more flexibility compared with normal BIM platforms. However, since some tools require compilation by the architects, architects should have broader knowledge of scripting and on how to intelligently use the appropriate tools, in order to gain the true benefits of a parametric approach.
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Figure 9. Photo of the National South China Sea Museum in the final stage of construction.

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