Inside Shan-Shui: A Case Study of Parametric Optimization Design based on Reception Aesthetics of Eastern Art

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Research Article

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Abstract

This paper explored the quantitative research methods of visual and aesthetic optimizing design through a parametric exhibition design case study, taking the eastern art (Chinese painting and Japanese Zen garden) as the source of aesthetic principles. It is difficult to optimize a visual problem because aesthetic qualities mostly involve subjective making decisions and intuitive judgments, in which there exist a huge design space with little restrictions. In our study, we firstly investigated the natural scientific essences behind the aesthetic problem, through literature review, to find out the principles of aesthetic quantitative computing: narrowing the scope of design space based on the figure-ground perception; constructing the optimization rule system through the medial axis transformation (MAT) model; defining the optimal objects by the dynamics analysis of Shannon information energy. And thus, we utilized the shape grammar exploring the figure design subspace and getting optimal seven foam sculptures, and in the ground design subspace exploration, applied the genetic algorithm conducting the multi-objective optimization and getting the optimal exhibition layout. Finally, we got the exhibition design with the essence of reception aesthetics of eastern art and implemented it.

Introduction

The primary purpose of this study is exploring how to use parametric optimization methods to optimize the visual and aesthetic problem through quantitative optimal principles based on aesthetic and perception theories. There have been various computational exploration and optimization methods applied in visual and aesthetic design cases (Alcaide-Marzal et al. 2020; Bianconi et al. 2020). Shape grammar is a rule-based algebraic methodology to calculate the optimal visual design (Stiny, 2006). Gun (2017) developed a generative painting system to incorporate computational technologies into processes of human creative visual exploration, making a step forward for shape grammar. Our study utilized the shape grammar as a rule system of figure-design subspace exploration.

Nevertheless, to optimize a visual problem is still a big challenge, what is natural and easy to do with our eyes and hands can be difficult to compute (Gun & Stiny, 2012). If the intuition and subjective experiences of designers can be translated into quantitative values, the design optimization process could be more objective and rational (Watanabe et al. 2019). Many related theories and work can be found (Leder et al. 2004; Jindo & Hirasago, 1997; Nagamachi, 1995; Ranscombe et al. 2012; 2012), such as Gestalt school investigate the correlation between physiological features and subjective aesthetic experience (Kovács & Julesz, 1994; Enquist & Arak, 1994). Tonder et al (2002) applied the Gestalt law, figure-ground perception, and the visual structure, medial axis (MAT model), found the implicit aesthetic response-inviting structure of a Japanese Zen garden. Watanabe et al (2019) utilized MAT model as visual brain to evaluate the aesthetic values quantitatively in car interiors. Our study applied the MAT constructing the rule system of ground-design subspace and defining quantitative optimal objects.

We converted the perceptual eastern aesthetic value into rational figure-ground perception principles and manipulatable visual structure (MAT model), thus paving the way for subsequent design space

exploration and quantitative studies. Moreover, we further explored the theory of Shannon information to interpret scientific principles behind the theories above to support our following researches. We referenced the studies of predecessors in this paper and regarded the figure-ground perception as an important optimizing principle for the exhibition space design, thus further expanded its methodological significances. In our study, we firstly investigated the characteristic of eastern aesthetics and explored the scientific perceptual principles behind through literature review. And then, we came up with the mathematical model to parametrize the aesthetic principle thus set up design variables and optimization objectives. Next, we explored the design space and decomposed that into design subspaces thereby simplifying the design issues and reducing the dimension of the data. Our overall research map as shown in Figure 1, and the specific procedures are detailed in following chapters.

Literature Review

Eastern Art's Characteristic: Emptiness and Uncertainty

Chinese Painting

As one of the highest expressions of traditional Chinese spirituality, Chinese Painting is a good example interpreting the notion of emptiness and uncertainty, in which the dialectic concepts of 'false but true, empty but full, and few but many' were often referred to and applied (Li, 2009). Emptiness is known as "white space", artist usually left some blanks in composition without any ink to enhance the overall visual effect of the painting and to facilitate viewers appreciate the artwork better, this "non-painting space" is a bridge of association and imagination connecting artists and audiences (Li, 2013). The notion of Emptiness is the heart of the Chinese painting worldview, which is the characteristic for making manifest philosophical concepts of yin and yang (figure and ground) embodied in Chinese aesthetics (Cheng, 1994). The unpainted blanks in Chinese painting resembles an empty bowl (Hara, 2003) where audiences can fill in blank with their own imaginations and ideations individually based on their distinct experience and intuition, thus empathizing, and communicating with the artist.

Japanese Zen Garden

Japanese garden design was deeply informed by traditional Chinese landscape painting and, after the Heian period, gradually formed a distinctly Japanese abstract character of Zen style that more simplified in comparison with their Chinese antecedents (Tonder 2018, Kuck 1968). Miniaturized sceneries in Japanese dry landscape garden are considered as original creations in the development of Japanese gardens, the emptiness of white sand is similar as the unpainted blank in Chinese paintings, the vacancy and the simple symbolic objects inspire profound insights and create sensory depth (Li, 2016).

Reception Aesthetics

The emptiness, blanks, and uncertainty in the eastern arts above can be explained by reception aesthetics: there exist emptiness, blanks, and uncertainty in any work of art, and the essence of art

appreciation is to fill in which. There are two fundamental parts in the reception aesthetics theory, one is the “Response-inviting Structure (Iser, 1978)” the other is the “Horizon of Expectation (Jauss, 1970; 1982)”. The former refers to an exquisite composition, an implicit structure, between the contents and vacancy in the artwork, which behaves an openness to arouse viewers to fill in the incomplete text by their imagination, such as the Chinese painting’s painted and unpainted compositions, as well as the rocks and white sand layouts in Japanese Zen garden. The latter is that audience who have different subjective expectations toward the artwork based on their individually distinct backgrounds and experiences appreciate and contemplate artwork at diverse horizons. The reception aesthetics assumes the artwork cannot exist alone but needs the audience participate in together, a work without being exposed to viewer’s appreciation is incomplete. Pelowski et al. (2017) studied the process in art perception and assumed that art-viewing is notable for its unique blending of a bottom-up process of artwork features with the top-down contribution of memory, personality, and context. The response-inviting structure generates a bottom-up mechanism, which arouses the viewer’s horizon of expectation, their own perception and memory, to appreciate the artwork, fulfill the blanks, in a top-down way.

Figure-Ground Perception

The reception aesthetic emphasized the significance of audience’s participation and proposed a connection between the artwork and the audience’s cognition and visual perception, and what the cognitive principle and the physiological essence behind which? The Gestalt school (Koffka, 1935; Wertheimer, 1938) gave the answer, they introduced the concept of visual perceptual grouping, known as segmentation, that the human brain groups together various visual cues into meaningful perceptual wholes. The segmentation process is the division of a scene into possibly meaningful parts by the early stage in the visual system (Driver et al. 1992). Koenderink et al. (1992) analyzed and divided the segmentation process further into surface regions and bounding contours of objects. At this level, local contour elements and surface texture elements are grouped into outlines and regions of segments, respectively. In the next step of perceptual grouping, the segmented image is arranged into figure and ground, which is known as Figure-Ground Perception (Wagemans et al. 2012). Accordingly, the unpainted blanks of Chinese painting and the white sand in Japanese Zen garden are the ground shape, it is because of the coordination of figures and ground that bring spectator a more wonderful visual experience and more imagination spaces. Tonder et al. (2002, 2005) conducted the quantitative analysis on the Japanese Zen garden (Ryoan-ji garden), through the figure-ground perception theory and the medial axis transformation (MAT) analysis model, revealing the implicit visual structure behind the garden layout; as well as the fact that the optimal visual structure can provide viewers at best viewing spot the maximal Shannon information. Tonder’s researches linked reception aesthetics to the information theory and introduced the Shannon information to quantify evaluation criteria for the visual structure in garden layout design.

Shannon Information Entropy

Shannon information, introduced by Shannon (1948), refers to “information”, “surprise”, and “uncertainty” brought about by specific happened events, and the information amount (see Formula 1) quantifies the level of which. The Shannon information entropy is the expectation of the amount of information that would generate before the events happen, considering all probabilities of the random variables, that of the expectation of the amount of information brought by all possible events (see Formula 2). In other words, entropy can be interpreted as predicting and estimating the level of “information”, “surprise”, and “uncertainty” inherent in events about to happen. The finding by Tonder that the optimal viewing spot can convey maximal Shannon information to audience means, in other words, this spot provides viewers maximal “information”, “surprise”, and “uncertainty” about the garden.

$$h(x) = -\log_2 p(x) \quad (1)$$

$$H(X) = -\sum_{i=1}^n p(x_i) \log_2 p(x_i) \quad (2)$$

In Shannon's theory, an information communication system is composed of three elements: a source of information, a communication channel, and a receiver (Shannon, 1948), and these three exactly correspond to figure, ground, and viewer, of the figure-ground perception system as referred above. The surprise and uncertainty that Shannon information focuses on coincides with the emptiness and uncertainty in reception aesthetics and eastern arts.

Methodologies And Design Implementation

Our study began with the aesthetic phenomenon of blank space in eastern art, exploring scientific principles behind which through literature research, thus conducting design space exploration based on theories that reception aesthetics, figure-ground perception, and Shannon information etc.

Design Space Exploration

Design space exploration (DSE) refers to the activity of exploring design alternatives prior to implementation (Kang et al, 2010). DSE is a methodology that translates real design problems into different variables linked through a rule system of design space, thus, to conduct optimization design and optimal solution search by adjusting parameters of the design space. The numbers of variables, namely design space's dimensionalities, is one of significant parameters, it is usually necessary to reduce the dimensions of design space to reduce complexity. In our case, we divided the design space into two subspaces, one is figure-design-space, the other is ground-design-space, according to the figure-ground perception principle, so that decomposed an intricate system into two relatively simple subsystem for the convenience of subsequent exploration and optimization procedures.

Figure-Design-Subspace

Shape Grammar: Ideation

Shape grammars are rule-based systems for describing and generating designs, shape computations are improvisational, perceptual, and action-oriented, they are underpinned by an algebraic theory that is a prerequisite to a general computer implementation (Stiny & Gips, 1972; Knight & Stiny, 2015). Gün (2016) extended the methodological significance of shape grammars and summarized the theory into the shape rules: part, boundary, and transformation; three simple formulas which can generate all the computational shape possibilities through their various combinations (see Formula 3,4,5).

- “Part” is that the novel shape is created by abstracting parts of the initial shapes

$$x \rightarrow \text{prt}(x) \quad (3)$$

- “Transformation” is that shapes are created by transforming the initial shape such as moving, rotating, flipping etc.

$$x \rightarrow x + t(x) \quad (4)$$

- “Boundary” is to abstract the outline or boundary of the initial shapes

$$x \rightarrow b(x) \quad (5)$$

By permuting and combining the three formulas above in all sorts of ways the shape rules can create ample and complicated shapes. At the beginning of our study, we made various compositions based on shape rules to conceive the designing shapes. We used the Chinese landscape painting as the initial shape computing input x and extracted the “parts” and “boundaries” from the visual elements in the painting to create new shapes. And then, we used parametric design tool to conduct shape grammar iterative design and got interesting ideas, the process in detail as shown in Figure 2. We overlapped graphic shape layers in parallel, that of 18 pages of “parts” in scheme A and 20 pages of “boundaries” of scheme B. Next, we finished the practical manufacture of two schemes by transparent film printing as shown in the right side of Figure 2. Among that, we completed the transformation from 2D to 3D by overlapping layers of graphic shapes, the corresponding shape rules’ operations of $t_3 \sim t_{20}$ in scheme A and $t_1 \sim t_{20}$ in scheme B.

In the next procedures, we extracted the element beyond the artwork contents, ex. The painting scrolls (canvas). And we also extracted the abstract mathematical formula behind the concrete forms of wave and texture in the painting as a way of shape transformation, that of the damped sine wave function (see Formula 6), by which we can parametrize the morphologies and adjust parameters thus for subsequent design optimizations. At this point, we completed two more conversions of the design: from the graphic shapes to solids, from qualitative composition to quantitative computing (see the upper part of Figure 3).

$$y = \left(\frac{1}{2} \right) \left(\frac{x}{h} \right) a \sin \left(\frac{2\pi x}{w} \right) \quad (6)$$

We can use 3D printing or fine carving technologies to complete the fabrication of such complex and concrete forms of scheme C, however, those figurative sculptures are not what we pursue in the study, and they run counter to the emptiness emphasized by eastern art. Accordingly, we proceeded with the damp sine wave function and explored abstracted design with minimalism style and least technological requirements. The process shown in the lower part of Figure 3, we gradually subtracted the concrete forms through the shape grammar. After 6 steps of transformations: $t_3 \tilde{t}_8$, we got an abstract solid with the wave texture in the one side and rock textures in the other side. Among them, the water wave textures were generated by the sine function, and the rock textures were formed by adding Perlin noise at the basis of sine wave function. Next, we duplicated the solid, and cut them into 7 pieces of solids with different sizes. Those solids have the self-similarities because their motherboard is just a bigger abstract solid like them. Thus, we could build a space in which there are 7 solids with similar styles and shape features as well as the empty grounds around them. At this moment, we had a figure-ground perception spatial system where we had the precondition and could conduct the ground-design-subspace explorations and optimizations, but before the ground design phase, we needed to further optimize the machine aesthetics of figure designs.

Machine Aesthetics: Optimization and Implementation

As we mentioned above, we applied the damped sine wave function to generate the water texture and added Perlin noise to represent the texture of rock. Therefore, we had a mathematical basis that could be converted to an adjustable parametric system, a design space with parameters and optimizing objectives, to optimize the design.

We planned to use the robotic arm hot line cutter and polyfoams to fabricate the design, the hot line cutting technology is efficient and low-cost for our project. Furthermore, its simple mechanism with minimalist style of machine aesthetics is a suitable way to represent the emptiness of what we want to interpret. We wanted to find out a fabricating tool that resembles a Chinese painting brush: pure and simple, instead of a high-tech multifunctional machine tool that can cope with various figurative and complex sculptures.

The molding mode of the hot-line cutter is to use a single wire to fit the curved surface, it itself is therefore a limitation of the fabrication, especially for organic or nonlinear form, which is a sort of machine aesthetic that the design forms are partly created by the machine limitation. The essence of machine aesthetics is that the machine participates in the process of form creation, and the form of machine processing is not an artificial design, but a natural result from the machine manufacturing process. The process of hot line cutting is the process of redesign or recreating for the design. The Chinese painting, or Japanese Zen garden, is also a process of redesign with a single brush and pure black ink, or simple rules and techniques, to present the complicated and vivid things, which is “less is more” that the artwork provides less specific contents to give the viewer more probabilities of information reception, that of Shannon information entropy.

In our parametric program, there were two fundamental parts, the first one is the shape grammars program as mentioned above, in which there were two main shape rules: one is the damp sine wave function, the other is the Perlin noise. The second part is the machine aesthetic optimization program, in which we applied the Kuka-prc plugin providing core algorithms, which helped us analyze the present design and gave feedback to the first part of shape grammars. Therefore, we could continually adjust the parameters of shape grammars algorithm and input iterative designing geometries to the second part thus getting the optimal design and tool paths for manufacturing (see Figure 4).

Before the manufacturing implementation, we went through the above iterative process many times and iteratively adjusted the design guaranteeing the solids with textures can be produced by the hot-line-cutting. Meanwhile, the machine aesthetics of the design were also optimized in the iterations, as shown in the Figure 5, from A1 to A6 is the simplification of water texture, and B1 to B6 is the rock texture optimizing process. Finally, we used KUKA robotic arm conducting the hot line cutting and fabricating the solids.

Ground-Design-Subspace

Figure-Ground Perception Optimization Ideation

As mentioned in the introduction, the figure-ground perception is the theoretical source of the reception aesthetics and the important reference for the ground-design optimizing principles. Tonder et al. (2002, 2005) applied concepts and methodologies of the figure-ground perception into studying the design and layout laws of Japanese Zen garden. They used the Medial-Axis Transformation (MAT) model as visual analytical tool to explore the implicit structure of the empty space (ground space) in the garden. They drew the hidden structure through the MAT visual analysis, see Figure 6-0, and found that the overall structure is a dichotomously branched tree that converges on the principal garden-viewing area on the balcony. In this tree, the main branch and subbranches have the self-similarities structure patterns, and the trunk passes close to the center of the preferred point from which to view the garden, along the trunk the view of garden provides maximal Shannon information about the scene. They proposed that this invisible design creates the visual appeal of the garden and was probably intended as an inherent feature of the composition.

Accordingly, we assumed that the above visual structure design laws could be applied into the ground-design-subspace exploration in our project, thus, to further develop a universal methodology for the layout optimization of exhibition design, especially for which where there are many exhibits. Meanwhile, the MAT model is an ideal quantitative analysis tool that can be parametrized in the computational design platform to conduct exhibition layout optimizing design. The work of Tonder et al. is revealing the hidden pattern behind the eastern arts, and our study is to apply this hidden pattern into the quantitative computational model to conduct the iterative optimization design applications.

Medial-Axis Transformation (MAT)

The formation logic of MAT model is similar with which of the Voronoi (Fabbri, 2002), and we used the Voronoi component in Grasshopper to rebuild the MAT model that Tonder's team made. By using the garden rocks' plane position coordinates as random points inputs of the Voronoi algorithm component, and using a larger rectangle, instead of the wall of garden, as the boundary of the Voronoi geometries, therefore the whole visual structure was generated. We found the MAT model they made, because of the garden wall, is just a part of the whole visual structure; there supposed to be the other three tree structures with converging branches in the whole model aside from that one crossing the best viewing point (see Figure 6-0). So here comes the question, whether the other three tree structures pass through the other three ideal viewing points? In other words, can we find out other three potential optimum viewing points, like the dash-circles in the figure 6-0, through these three branches?

To answer the questions above and to find the regularities of optimal visual structure, we conducted the simulations of visual information diffusion in the Rhino (Grasshopper). The first, we need to understand the geometric generating principles of MAT (Voronoi) model: imagining there are many random points in a plane region, which called control points; drawing circles with each control points as the center; adjusting all the circles radius enable them synchronously grow bigger; as these circles get bigger, they gradually intersect; when intersected, they were squeezed and the arcs become straight lines; finally, when all the arcs became straight segments, the MAT model form.

As shown in Figure 6-1 to 6-6, we applied the above MAT generating process in the garden Tonder studied, taking the five rock clusters as control points (R1~R5). The circles generated from the five center points here could represent the visual information energy emitted from the five figures. At the beginning of the MAT formation process, five circles were independent from each other and had not intersected. With the transformation proceeding, there appeared the first intersected point P1 from which can acquire the equivalent amount of energy from the points R3 and R4 (see Figure 6-1). Immediately after, the point P1 transformed into a segment and extended itself to intersect with the P2 extension line at the point P3 which is the intersection of three circles (cells), and from which can get the same amount energy from the three points R3, R4, and R5 (see Figure 6-2). In the next phase, circle R1 and R2, as well as circle R2 and R3 all had intersections, respectively were P4 and P5, and they began to extend themselves into the lines (see Figure 6-3). One of the definitions of the Voronoi is that any points on one edge of the Voronoi polygon is equally distanced from the control points of the two cells adjacent to that edge. Therefore, in our simulation this equivalence of distance can be understood as the same amount of energy obtained. Every intersected edge represents the convergence of energy from the two adjacent control points, they originated from the initial intersected points and extended themselves to the two directions of two ends. Among them, in the Figure 6-4, the line P3 is the converging line of line P1 and P2, so it represents the energy from the three points R3, R4, and R5. Meanwhile, three energy collecting lines P3, P4, and P5 all have the tendency extending to one same direction which was the red rectangle's location in Figure 6-0 and the best viewing spot in principle of the garden as well. From this stage, it could be speculated that the red square (or the trunk A in Figure 6-6) supposed to be the point where the energy of five control points converged. In the Figure 6-5, every energy line proceeded to extend, line P4 and P5 intersected at point P6 and then converted to line P6, and the line P6 intersected with the extension line of P3 at point

P8. Point P8 was the maximal Shannon information point, at this point it gathered all the energy of five control points, but when the P8 began to extend into the line, after the P8 point, the energy would damp. Finally, in the Figure 6-6, all the trunks and the whole visual structure formed, experiencing the whole formation process, we could conclude the visual information energy amount comparison of four trunk A, B, C, and D: the trunk A had the maximum energy, which from all 5 control points; trunk C ranked second, because it was the convergence of three points R2, R3, and R4; trunk B and D tied for third, trunk B got energy from point R1 and R2, and trunk D from R4 and R5.

We concluded the ideal MAT visual structure regularities based on above simulation. First, trunks can get more energy. The point on the trunk can provide more information energy than other positions, because the trunk is the energy convergence line of at least two adjacent control points, if there were better converge structures, Y-shaped structure for instance, the numbers of corresponding control points will be more. Second, convergent Y-shaped branching structures. The Y-shaped structure is the dichotomous branching structure where the two secondary branches are at acute angles to the primary branch extended line (or at obtuse angle to the primary branch itself). As shown in the Figure 6-6, there are three Y-shaped branching structures in the tree A (that of A-P8-P6-P3, P8-P6-B-P7, P8-P3-P7-D respectively, as well as $\angle P_6P_8A$, $\angle P_3P_8A$, $\angle P_4P_6P_8$, $\angle P_7P_6P_8$, $\angle P_7P_3P_8$, and $\angle DP_3P_8$, all are obtuse angles), the trunk and the first-level two branches compose a Y-shaped structure, and the two first-level branches with four second-level branches make up the other two Y-shaped structures. It is this Y-shaped tree structure that allowed energy to flow from five control points to the trunk. There is just one Y-shape structure in the tree C to such an extent that the trunk C can get three points' energy. There is no Y-shape structure in the tree B and D, so that the trunks just get information from their adjacent two points. Third, the nodal point where the tree bifurcates into the first two branches, is a location of maximal global Shannon information. As mentioned above, in the tree A the energy obtained in the intersected point P8 is more than which get from points on the trunk A. The point P8 distances equally from the points R1, R3, and R5, while points on the trunk A have equal distances from points R1 and R5, the distance from R3 is uncertain, according to the definition of the Voronoi. Meanwhile, common sense dictates that the further away we are from a work of visual art, the less visual information we should have. Accordingly, the further away from the control points, the lower the visual information energy obtained.

To sum up, we had three optimizing principles from MAT analysis above, as following:

- Maximizing the number of tree-trunks and orienting them evenly distributed along the viewer path.
- Maximizing the number of Y-shape structures.
- Minimizing the distance between the first dichotomous joint and viewer path.

Optimization Objectives

Based on the above simulations and analysis, this phase, we converted the conclusions above into the optimization objectives. The parametric optimization tool we used is the Octopus (Vierlinger. 2013) plugin which embeds the genetic algorithm as the core optimizing iterative algorithm. Its operation mechanism

is to search the minimum of objective function through cycle iteration. Meanwhile, the visual structure (MAT model) in our program was drew by the Voronoi algorithm which not including such as trunks and Y-shape structures etc. Therefore, we needed to simplify furtherly optimizing principles above into easier optimization objectives that can be manipulated conveniently.

Through analysis we assumed if there were at least one closed Voronoi cell in the exhibition area, and maximizing the area of this cell, the above three optimizing principles can be realized in a high probability. For instance, in the Figure 7-1, there is one closed cell inside the boundary, around which with branches pointing in all directions, so it is easier to form trunks with different orientations. Meanwhile, each corner of the cell could, with high probability, form a Y-shape structure with trunk and branches. In addition, if we maximized the area of the cell, as Figure 7-A, corner points get closer to the boundary and could convert to the potential first dichotomous node (the maximal Shannon information point) near the viewer path.

We also found that, in a Voronoi with a boundary, the number of trunks (NT) and closed cell (NCC) as well as the number of all control points (NCP) have the following relationship in the Formula 7. That is, NT and NCC have negative correlation.

$$NT = NCP - NCC(7)$$

To confirm how many closed cells inside the boundary are appropriate, we conducted more specific quantitative analysis. In our case, we had seven objects through the figure-design ideation, so we analyzed the MAT model composed by seven control points, thus, attempt to find out more universal design optimizing principles of figure-ground perception. Therefore, as shown in the Figure 7-0 to 3, we enumerated all possible scenarios based on the number of closed Voronoi cell inside the rectangular boundary.

In the Figure 7-3, there are three closed cells, it was the extreme case that in a quadrilateral area, four control points corresponding four boundary edges respectively, and the rest of three points assembling in the center. This is the case where the number of closed cells inside the rectangular boundary is the largest in all possible situations. According to Formula 5, the more closed cells the fewer trunks, so this is also the case with the fewest tree trunks. We could also find through observation, in this situation there is no trunk goes through around the two short boundary lines. Meanwhile, the layout of seven points was so symmetrical that lack of natural aesthetics and too fixed to form other alternatives.

Another extreme situation is that, as the Figure 7-0, there is no closed cell inside the boundary. According to Formula 5, the number of trunks is equal to which of control points, reaching the maximum. However, all the first dichotomous points are centered and away from the boundary to such an extent that it is difficult to form the maximal Shannon information point, which also confirmed our previous hypothesis that closed cell could provide the potential maximal Shannon information point more easily.

Among the remaining options, “one” and “two” closed cells, we finally chose “one” (see Figure 7-1 and 7-2). The first reason, in a specific rectangle, it is common to see enclosed cells that are not completely inside the rectangle. For instance, as Figure 6-0, the visual structure of Tonder’s garden where there is a closed cell, but the upper and lower corners are beyond the bounds of rectangle wall. Therefore, if set “two” as the optimizing goal, the computer will only help us search models with only two closed cells in the rectangle, we would loss many potential good visual structures. Second, through observations we found the points layout from one enclosed cell scheme is more flexible and ample. The layout feature of points around a closed cell is that there is one point in the center surrounded by the rest of points, and that of no closed cell is that there is an empty space in the center with points surrounding. Both features can be found in the single closed cell structure and seldomly appear in the bi-cells one. In other words, mono-cell model is the eclectic between non-cell and bi-cell structure and contains both features of which.

To sum up, we got the two optimizing objectives for the subsequent iterative optimization, that of the first is to let the number of enclosed cell inside the boundary be one; the second target is too maximize the area of the closed cell. Meanwhile, we also had a quantitative evaluation criterion that of comparing the number of Y-shape structures in the models.

Multi-objective Optimization: Speculation

We utilized the Grasshopper and genetic algorithm plugin Octopus conducting the multi-objectives iterative optimization. In the Grasshopper we built a MAT model through the Voronoi component with seven control points, and random seed value ranged from negative infinity to positive infinity to exhaust all possibilities of seven control points layout in principle. And we sorted the seven solids of figure-design in order of their volume from small to large and oriented them to corresponding seven Voronoi cells in order of each cell’s area. Finally, we set the two optimizing objectives in the Octopus: one is let the number of closed Voronoi cell inside the boundary equal to one, the other one is maximizing the area of which. Accordingly, when the optimization started the seven control points moved automatically, searching the optimal MAT model iteratively, thus enable which to fit the one that meet the objectives we set. Meanwhile, the seven solids were also distributed reasonably to corresponding cells where fit their sizes. After a period of iterative optimizations, we got the optimized designs, as shown in Figure 8, and adopted the top five results from the overall ranking list for further analysis and design (see Table 1).

Table 1
The top five results of optimizing score ranking list

	Parameters	Optimizing Objectives		Evaluation
#	Random seed	Cells Number	Single Cell Area	Y-shape Number (Non-repeat)
1	23769	1	5748564	14 (9)
2	78220	1	5509449	26 (15)
3	-54455	1	5461643	31 (16)
4	4945	1	5388481	8 (8)
5	-97325	1	5173641	6 (6)

Aside from the above two optimizing objectives, the number of Y-shapes was taken as the evaluation criterion for optimal design. We counted and marked the numbers of Y-shape structures for the five schemes respectively, finding which from schemes 2 and 3 were obviously larger than other threes (see the upper right part in Figure 8). Meanwhile, there were unreasonable extremely short branches in the scheme 1, 4, and 5 (in the dash circles shown in Figure 8), and we assumed that these weird structures might contribute indirectly to the poor performance of the overall structures where they were. Accordingly, we would take the length range of every edges into account in the subsequent optimizations.

Exhibition Layout Arrangement: Implementation

Our project was selected for participating in the 5th Art and Science International Exhibition that happened in 2019 at the National Museum of China. The real exhibition place in museum, where there were restricted conditions added, was distinct from our speculative design space. First, we no longer had an all-side-open square for the exhibition, instead, a confined space behind the wall. There were two entrances on the wall as the main flow channels for visitors. Second, we were demanded to hang on a TV on the wall behind to display the detail information of our project.

We firstly analyzed the impact of the second restriction, the TV. Aside from the prefabricated seven solids, counting TV, now we had eight stuffs in the exhibition area. However, according to the Gestalt law of good continuation, odd-numbered groupings (junctions) of items are preferred (Tonder et al, 2005). Therefore, at the basis of eight items, we added a Chinese painting work of our collaborating artist, which is our project's inspiration and the initial x of shape grammar, to make up nine objects and meet the odd-numbered junctions principle. In addition, this painting, with TV, could better interpret our ideas and design concepts.

As for the impacts of background wall. Firstly, there were two entrances on the wall, so we considered how to utilize them coordinated with the visual structure to attract more visitors' attention when they were passing by. For instance, an optimizing objective could be two trunks are needed to pass through both entrances respectively at the same time thus making the entrances' locations receptive to more visual

information energy. Secondly, there were three tall solids among sevens, which easily to obscure the information (TV and painting) on the wall. Accordingly, we chose two of them only leaned against the wall, when the optimization process started, they could only move along the wall.

Besides, at this moment we had two types of visual figures, one type are seven white foam solids with minimalist style, the other type are the stuffs on the wall, the TV and painting, with colorful, animated vivid visual information. They had different types of location and visual information. Therefore, we decided to divide the whole optimization process into two phases, the first phase purely optimizing the seven foam solids based on the figure-ground perception principles same as used in the above speculation studies. The second phase is that when optimal layout of seven foams confirmed and fixed, adding painting and TV, iteratively optimizing the nine-object-system by only moving painting and TV, based on the optimizing principle with restricted conditions. To such an extent that there would be two sets of optimal visual structures corresponding two distinct versions of optimizing principles in one exhibition space, one is the speculative version of seven foams based on pure principle of figure-ground perception, the other is the grounded version of all nine elements to meet the restrictions from the museum, the latter is the revise version for the former.

Based on the adjustments above, we conducted the final exhibition layout optimizing design (see Figure 9). We had two optimization phases with corresponding different optimizing objectives and iteration approaches. In the first phase, we proceeded with the two optimizing principles of speculative design, that of letting number of closed cells inside equal to 1 and maximizing the area of the closed cell inside. In the parametric program, we regulated the two tall and slim solids only moved along the wall, and the rest five were still controlled by random seeds. To avoid these two solids to collide or overlap, we added the program an anti-collision mechanism that letting the intersection of two solids' bounding box equal to 0 (see Figure 9-I). After a period of program running, we got the optimal design, as Figure 9-1a shows, of which at the basis we conducted the second phase of optimization.

In the second phase, the parametric program only moved the two control points, of TV and painting, along the wall and enabled the whole visual structure of all nine objects, including TV, painting, and seven foams, to fit the optimization objectives of this phase. Among that, the first two optimizing objectives were same as which of previous phase. And the third objective was to avoid the TV and painting being obscured by foams in front, we extended them as two boxes and set the objective was that their intersections with all foam's bounding box equal to 0, thus to correct when they collide with the solids. In addition, we also needed to avoid painting and TV colliding with each other, so we set anti-collision mechanism, the fourth objective, for them that 0 intersected points between their bounding boxes (see Figure 9-II). The fifth optimizing principle was to attract the attention of people at the entrance, mentioned above, so we set the objective that maximizing the intersected points between entrance lines and Voronoi edges (the trunk). In the end, we got the final design through the second phase of iterative optimization (see Figure 9-2a).

Table 2
Details of exhibition layout optimization in the stage of implementation

Optimizing Objectives		Evaluation	Iterative Program
Phase 1	$O_{11} = \min_{-\infty < s < \infty} \{ NCC_1(s) - 1 \}$	$O_{11} = O_{13} = 0$	Seven control points of the Voronoi, in which five moving randomly inside the boundary and two along the wall.
	$O_{12} = \max_{-\infty < s < \infty} \{ ACC_1(s) \}$	$\max \{ O_{12} \}$	
	$O_{13} = \min_{0 < d_1 < 10} \{ NI_1(d_{11}, d_{12}) \}$	$\max \{ NY \}$	
Phase 2	$O_{21} = \min_{0 < d_2 < 10} \{ NCC_2(d_{21}, d_{22}) - 1 \}$	$O_{21} = O_{23} = O_{24} = 0$	Fixing optimal layout and corresponding seven control points, adding, and moving two points of TV and painting along the wall, thus optimizing the whole visual structure of all nine points.
	$O_{22} = \max_{0 < d_2 < 10} \{ ACC_2(d_{21}, d_{22}) \}$	$\max \{ O_{22} \}$	
	$O_{23} = \min_{0 < d_2 < 10} \{ NI_{21}(d_{21}, d_{22}) \}$	$O_{25} = 2$	
	$O_{24} = \min_{0 < d_2 < 10} \{ NI_{22}(d_{21}, d_{22}) \}$		
	$O_{25} = \max_{0 < d_2 < 10} \{ NI_{23}(d_{21}, d_{22}) \}$		

The above optimization processes are summarized as shown in the Table 2. Among that, the function NCC is the number of closed cells inside and the ACC is the area of the closed cell, both functions are based on the Voronoi algorithm: in the phase 1, the variable of random seed (s) ranged from $-\infty$ to ∞ , and in the phase 2, two variables are painting's and TV's moving distances along the wall, which of d_{21} and d_{22} respectively, ranged from 0 to 10 meters. The function NI means number of intersections: in the phase 1, NI_1 is the intersections' number between two tall foams' bounding boxes, its variables d_{11} and d_{12} represents the two tall foams moving distances along the wall respectively, ranged from 0 to 10 meters. In the phase 2, NI_{21} is the intersections' number between seven foams and things on wall (TV and painting), NI_{22} represents the intersections between TV and painting, and NI_{23} is the number of intersected points between entrance's line and Voronoi edges, all functions in this phase are based on two same variables, d_{21} and d_{22} , the moving distances of painting and TV along the wall, ranged from 0 to 10 meters.

Before the final exhibits arrangement, we made one final adjustment to the layout, as shown in Figure 9-1b and 2b, we moved the leftmost foam to enable the main branch (trunk) at the upper left corner to form acute angles with its two secondary branches, thus to get one more local Y-shape structure. However, reasonable though the nine objects' visual structure was, that of seven foams where the closed cell inside

beyond the upper boundary. Due to the existence of the background wall, we didn't have to consider the visual structure behind that. Thereby, both visual structures of either seven foams or nine all objects were optimal, and we used the final optimal design as the blueprint for the exhibition implementation.

Design Implementation Results

We conducted three groups of control experiments before the formal implementation of optimal layout design. We invited two co-designers and a co-artist designed and arranged three distinct layouts manually through their intuitions, as shown in Figure 10.

Among that, the first scheme was three big cubes close to each other, in which seven solids' elements were reorganized. This scheme lacked empty spaces and visual conjunctions running counter to the receptive aesthetics we were pursuing. The simple and crude compositions of three big cubes failed to form the emptiness and uncertainties, with zero Shannon information entropy that provided no space for viewers' imagination. The second scheme composed by seven solids formed spatial area and visual junctions. However, its layout and visual structure were symmetrical, thereby eliminating the uncertainties and the natural beauties, and similarly difficult to form enough Shannon information entropy and imagination space for viewers. The third scheme was designed by the artist, he added more randomness into the design, the overall layout was indeed improved without the excessive symmetry and dull of previous two schemes, and viewers also could feel uncertainties and more imagination space from that. Nevertheless, it had some obvious disadvantages, for instance, from perspectives of the Figure 10-3, at least two objects in each picture were occluded by others by more than 80%, which caused a great loss of visual information, thus reducing the likelihood, Shannon information entropy, of the viewers receiving the information. It is as if a painter used a good deal of ink and brush, but painting the contents overlapped so that viewers cannot recognize or loss many information, and the overlapped painting contents were either not what artist wanted to express initially. In addition, this scheme's space utilization was not ideal either.

After trying our intuitionally designed exhibition arrangement scheme, we took the parametric optimal design plan into implementation, as shown in Figure 12. Compared with control groups, the final optimal design had three prominent advantages. The first, the overall layout was natural and asymmetrical, and fully utilizing the exhibition space. Among the control groups, the first two schemes had strong artificial trace, which lacked uncertainties thus depriving viewers of expectations and imaginations toward artworks. Furthermore, the space utilization of the three control groups were worse than the final design. The second advantage, the optimal scheme had a better information conveys to viewers. In the three control group schemes, the first two exposed all information to viewers thereby without any uncertainties, that of Shannon information entropy equaled to zero, while the third scheme hid excessive information thus many significant visual cues were missing and conveying incorrect information to viewers. It was indeed most difficult part that conveying information based on reception aesthetics of uncertainty, need to hide a part of information but not too much. Accordingly, the power of computational design and optimization were brought into play at this moment. In the final design, aside from two special trunks that passed through entrances, all three main trunks in front met design expectations of getting maximized

Shannon information; when viewers pass by these three trunks along which to see the exhibitions, they can be exposed to all nine objects, on the other hand, when viewers were watching from other locations, there was always an object blocked by other (see Figure 11). Furthermore, the three trunks were arranged along the viewing path evenly, thereby when viewers were walking along the viewing path, they would experience repeated switching process between visible and invisible, certainty and uncertainty, and seeing and imagining as well. In addition, the third advantage is that the computational optimizing design method is much more efficient than traditional way. We could conduct the absent (off-site) design when we got related information and data, and speculate the optimal solutions through design space exploration, finally arranging the preproducing artworks in the exhibition area according to the optimal blueprint.

Discussion

Digital redesign for eastern arts based on aesthetic essence

Discussion

The present and existing digital design projects with theme of eastern arts, Chinese painting etc. mainly discussed how to improve the digital technologies to simulate the techniques and formalist style of which. Lam and Yam (2009) proposed a brush footprint model and conducted a digital art experiment that can simulate the calligraphy of famous Chinese ancient artists. Yao and Shao (2005) invented a Chinese robotic painter that can imitate the artists' behavior and draw bamboos. Ma and Su (2017) proposed a stroke reasoning methodology for robotic Chinese calligraphy. The British Museum explored the multiple perspectives in Chinese painted scroll through an immersive video (2018). ChipGAN (2018) improve the style transfer machine learning model enable works of which to have more Chinese painting style. However, they failed to grasp the essence of eastern art, the concealing pattern inhere behind art forms.

Contribution

What is the essence of eastern art? Is it the unique rice paper and brush of Chinese painting? Or is it the rocks and white sand in the Japanese dry landscape? The reason why we put the both, Chinese painting, and Japanese Zen garden, together into comparison is just to avoid that we would regard one certain tangible element from one of both as the essence of overall eastern art. The comparison between Chinese painting and Japanese Zen garden is a good example, they have different medium, material, and distinct tool, and context, even their spatial dimensions are divergent, one is the two-dimensional graphic painting the other is the three dimensional landscape garden. However, both follow and adhere to the one same aesthetic principle: reception aesthetics, and both have the characteristic of emptiness and uncertainty, that of their common essence. On this basis, we can conduct digitalizing redesign by applying digital technique tools and novel media, because the authentic essence is not a certain tool or a specific medium. If the essence, reception aesthetics, remains the same, the novel digital artworks are still

eastern art. In other words, the clarification of the eastern arts' essence is the pre-condition of digitalizing redesign.

In our study, we explored the mathematical logics of implicit patterns, the essence, behind the form and style of eastern arts and applied which to redesign of machine aesthetics, and optimized design based on visual perception principles. At the beginning of figure-subspace exploration process, we started with extracted specific elements and shapes from painting through shape grammar ideations, many concrete novel shapes were composed but difficult to further expand the design space and optimize through which. Therefore, we turned to extract the damped sine function, a math logic and morphogenetic essence behind the water wave form, as a quantitative and manipulable variable for subsequent shape grammar calculating and machine aesthetic optimizing process. In the ground design subspace, we applied parametric MAT model conducting multi-objectives optimization based on the scientific essence of reception aesthetics: visual perception principles and Shannon information theory.

Aesthetic Optimizing Issue

Discussion

There are many design cases refer to visual and aesthetic optimization, but few of them succeed in constructing a rational quantitative optimizing objective. Lo et al. (2015) utilized the Kansei engineering and Fuzzy evaluation establishing an aesthetic criterion thus applied the genetic algorithms, combined with which, to product form optimization. But the Kansei vocabularies they used (Balance, Equilibrium, Symmetry, Proportion, Unity, Minimalist) are still stuck in the representation and perceptual description of feelings. Yousif et al. (2017) proposed a novel approach accommodating designers' aesthetic judgment into the whole architectural design optimization process. However, this evaluation system still established on the subjective aesthetic judgment by the architect interaction with which. Kenya Hara (2021) adopted a quantitative design method and defined the rule system and design variables but relied on personal aesthetics experience and intuition in the design evaluation phase. Computational optimization requires quantitative metrics to run, and thus, subjective decision making, and visual aesthetic issues cannot be easily be quantified (Gun, 2017).

Contribution

There are two main difficulties in the visual and aesthetics optimization, one is the huge design space with very few restrictions, the other is that the subjective decision making cannot be easily converted to quantitative optimizing objectives. In our research, in response to the first problem above, we investigated the essence of eastern esthetics, to find the basis of design space division, and divided the whole design space into two design subspaces through the figure-ground perceptual principle, and thus, adding boundary conditions to the whole design space and narrowing the scope of feasible solution space. For the second problem, on the one hand, we utilized the visual structure (MAT model) as the rule system of the ground-design subspace and combining Shannon information theories (information energy dynamic analysis) getting quantitative optimizing objectives; on the other hand, we applied the shape grammar as

figure-design subspace's rule system and getting optimal design through KUKA|prc analysis. We quantified the subjective and perceptual problems into the specific, quantitative, and manipulatable optimizing objectives, exploring the probability of solving the aesthetics visual design issues through computational optimizations.

Declarations

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Data and code availability: Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest: The author declares that there is no conflict of interest.

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Figures

Figure 1

Research Map

Figure 2

Initial design explorations through shape grammar

Figure 3

Getting the optimal figure-design form through shape grammar exploration

Figure 4

Parametric texture optimization of the figure-designs to be processed by hot-wire cutting

Figure 5

Texture iterative optimal results and the hot-wire cutting process

Figure 6

The dynamic analysis of the flow of visual information energy for the Ryoan-ji garden

Figure 7

Visual structure analysis

Figure 8

Starting from the end of each trunk, count how many Y-shaped dichotomous structures where the two secondary branches are at acute angles to the primary branch

Figure 9

The final optimization for exhibition layout implementation

Figure 10

Three control group schemes

Figure 11

Five optimal viewing spots along trunks of visual structure

Figure 12

The final effect of the exhibition at museum