Research on Artistic Design and Functional Adaptation of Community Public Space Layout under the Influence of Theater Culture

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Abstract This study takes theater culture as an entry point to explore its innovative application in the artistic design and functional adaptation of community public space. A spatial layout model is constructed through parametric design techniques and fractal curve theory, functional adaptability is verified through eye tracking and questionnaire survey, and structural equation modeling is utilized to reveal the enabling mechanism of theatrical culture genes on public space layout. The dimension of cultural communication satisfaction scored the highest in Study Area A, with a mean value of 3.91 points, and the mean values of the five dimension scores in descending order were as follows: cultural communication satisfaction>emotional perception>satisfaction with artistic expression>satisfaction with the type of public art>accessibility. The CMIN/DF value of the modified functional adaptation model is 1<1.258<3, the value of GFI is 0.923>0.9, the RMSEA is 0.032<0.05, and the values of AGFI and NFI are all greater than 0.9, and each adaptation index meets the requirements, which indicates that the model fits well, and confirms that the 5 dimensions are the core dimensions of functional adaptation.

Index Terms theater culture, community public space, fractal curve, eye tracking, structural equation modeling

I. Introduction

In modern urban planning, building livable communities is the key to improving the quality of life of residents, and promoting the optimal allocation of public space in urban communities has also become an important part of urban planning, spatial governance, and social service expansion in the new era [1]-[4]. The design of community public space is closely related to the daily life of the residents, but according to the current status of the design of community public space, there are still a lot of practical problems that need to be solved.

At present, the urban community in the configuration of public facilities on the differentiation of residents' needs lack of consideration for the individual needs of different residents is difficult to fully meet. For example, health service stations, fitness equipment, public toilets, landscape parks, etc. needed by the elderly, and sports grounds, tram charging piles, parking spaces, convenient post stations, foster care points, employment service centers, etc. needed by young people are in a lack of or imperfect state, and the types of community public service facilities as well as the spatial layout should be optimized and adjusted in terms of design [5]-[7]. In addition, the design of urban community public space gradually tends to be patterned and homogenized, which only meets the housing needs of the residents, but neglects to consider the design of green environment, fitness activities and other areas and the display of cultural elements [8]-[10]. Community public space lacks due interactive interaction functions, resulting in a weak community interaction atmosphere, reduced interaction and communication among community residents, diluted neighborhood relations, and reduced residents' sense of belonging to the community and willingness to participate, which is not conducive to the internal unity of the community [11], [12].

Drama is an important part of the spiritual and cultural life of the city, which can reflect the content of urban life and social customs, embody the spirit of the city, and counteract the development practice of the city [13], [14]. In community activities, theatrical forms of activities are integrated, especially opera face painting type activities, which attract residents to stay longer, and put forward new demands for community public space.

This paper first systematically explains the systematic strategy of community public art design, emphasizing the technical value of parametric design in promoting multicultural symbiosis. In-depth analysis of the technical logic of fractal curves provides mathematical tools for the spatial translation of dramatic narratives. Take Hilbert curve and Piano curve as examples to demonstrate their topological advantages in space filling and path generation. Take the study area A as a case study to start the analysis, and use the eye-tracking technology to quantify the attractiveness of spatial nodes. Combined with the structural equation modeling, the influence mechanism of functional fitness of

public space layout is examined.

II. Artistic design of the layout of community public spaces

II. A. Connotations and Strategies for the Overall Design of Community Public Art

As a complete system, urban community public art not only presents a static structure, but is also in a constant state of development, evolution and renewal. From its composition, it can be seen that, in addition to the relative stability of the morphological structure, the other two structural levels (social structure and activity institutions) have great variability, and can still provide vitality for the construction of public art in the area for quite a long time after the completion of the community. Therefore, our research on the overall design of community public art should not be confined to the exploration of the material form.

At the same time, as a subsystem of urban public art network and an important branch of urban community construction, community public art system cannot exist independently from the peripheral environment. Therefore, the research on the overall design of community public art should not only be satisfied with being self-contained, but also penetrate into the public cultural construction system of the whole society, and seek to harmonize with the general environment of the city and the overall pace of human social development.

To summarize, the connotation of the overall design of urban community public art should include at least the following three levels:

(1) Improve the hierarchical structure of the community public art system, strengthen the integration and balance between the constituent elements, and realize the integrity of the construction of the urban community public art system;

(2) Strengthening the continuity of the various stages of community public art construction, establishing flexible and changeable creative ideas and sustainable ecological design principles, and leaving room for the self-growth of the community public art system;

(3) Focusing on the connection between the internal and external systems of the community, giving full consideration to the factors of local culture and social environment, and reflecting the unity between the community public art system and the existing state and development planning of urban public art.

It can be seen that the overall design of community public art is a complex and systematic long-term process, involving various levels of social factors, depending on the professional designers or a group of forces individually difficult to grasp the completion. However, the current design status of community public space in Chinese cities urges us to come up with practical and effective strategies as soon as possible to establish a perfect urban community public art system.

Considering all factors, this paper suggests that the overall design of public art in Chinese urban communities can be deepened from the following three aspects:

(1) The creation of a unified and diversified community public art material form structure;

(2) The planning and organization of rich and lively community public art activities;

(3) The design and construction of scientific and democratic community public art mechanism.

Due to the limitations of the nature and mission of the design art discipline itself, the exploration of the overall design method of community public art in this paper will mainly focus on the creation of the material form structure, and at the same time put forward some constructive opinions on the planning and organization of community public art activities and the design and construction of related mechanisms, with a view to making the research of "overall design of community public art" more complete and possible to make the research of "overall design of community public art" more complete and possible. At the same time, we will put forward some constructive suggestions on the planning and organization of community public art activities and the design and construction of related mechanisms, with a view to making the research on "overall design of community public art" more complete, and possibly providing some clues for the comprehensive construction of urban public art system.

II. B. Parametric Design in Contemporary Public Art

It is in the complex and diverse cultural system that parametric design is born. It is not only just an intermediary between people and the digital world of information, but also a carrier. A series of design languages and design logics generated by it not only have the characteristics of international cultural symbols, but also satisfy the demand for the compatibility and coexistence of local and global cultures, traditional and modern cultures, enrich the connotation of visual culture, and increase the diversity of people's aesthetic choices and spiritual consumption needs.

Any major achievement of exploration in the scientific world will have a profound impact on the development of art. Just as the Industrial Revolution brought about Modernism and the Bauhaus, when contemporary public art encounters digital smart technology, it will inevitably produce artistic logic and design methods that conform to the

new technological context. In fact, since the 1970s, under the guidance of non-linear science, the concept and idea of parametric design has been influential in many disciplines, such as art and architecture, etc. Parametric design's re-understanding and redefinition of the concepts of simplicity and complexity, determinism and randomness, and order and disorder has also prompted more and more designers and artists to try to subvert the determinism and monotony of conventional linear thinking The concepts of randomness and chance have also prompted more and more designers and artists to try to subvert the certainty and monotony brought about by traditional linear thinking, and to dedicate themselves to using randomness and chance to interpret new concepts of art design.

In contemporary public art creation, artists and designers can use computers to set up logical parameterized programs, which are operated by art participants to generate public art behaviors, in which the dissemination, change, and result are completely open, adjustable, and non-linear, rather than being completed in a step-by-step manner. In art activities, the public's participatory behavior can create a multi-dimensional group art experience beyond the individual limitations of the artist, and this art process has the very typical characteristics of "emergence" and "generation", from nothing to something, from low level to high level. From simple to complex, it is interaction, behavior and self-organization. Compared with traditional art that emphasizes the work itself, this kind of art is a feedback to the change of human life style and paradigm, satisfying the needs of both the artist and the art participants, and it is a brand-new art concept, art logic and art language.

III. Analysis of key techniques for the layout of community public spaces -- fractal curves

Definition of a space-filling curve: a map $f : I \to E^n (n \geq 2)$ is continuous and $f(I)$ has a positive PeanoJordan measure. Then $f(I)$ is called a space-filling curve, where E^n denotes an n-dimensional Euclidean space.

Definition of Hilbert curve: assuming that I and Q are the intervals $[0,1]$ and the squares $[0,1] \times [0,1]$, respectively, the Hilbert curve is generated as follows:

$$\mathrm{H} : t \in [0,1] \mapsto \mathrm{H}(t) \in [0,1] \times [0,1], t = 0.q_1 q_2 \cdots, 0 \leq q_j \leq 3 \tag{1}$$

$$\mathrm{H}(t) = \begin{pmatrix} \mathrm{R}e \\ \mathrm{I}m \end{pmatrix} \lim_{n \to \infty} T_{q_1} T_{q_2} \cdots T_{q_n} \mathrm{Q} \tag{2}$$

where t is denoted by a quaternion. Define $\{T_i \mid 0 \leq i \leq 3\}$ as follows:

$$T_i = \frac{1}{2} H_i z + h_i, 0 \leq i \leq 3 \tag{3}$$

In this paper, we introduce the following expressions $H_0 z = \overline{z}i$, $H_1 z = z$, $H_2 z = z$, $H_3 z = -\overline{z}i$; $h_0 = 0, h_1 = \dfrac{i}{2}$, $h_2 = \dfrac{1+i}{2}$, and $h_3 = \dfrac{2+i}{2}$. where this chapter considers the complex $z \in \Box$ as $(Re(z), Im(z)) \in Q$. Put these four transformations $T_i \mid 0 \leq i \leq 3$ corresponding to different geometric deformations, respectively. Taking the transformation T_0 as an example, the original Q is first scaled down toward the origin by $\dfrac{1}{2}$, then multiplied by -1 to reflect on the imaginary axis, and multiplied by the imaginary number i to rotate the square by 90 degrees. During the generation of the Hilbert curve, the subsquare shrinks to a point, which indicates that $\mathrm{H}(t)$ is a point in $\Box^2$. The n th approximation of the Hilbert curve is constructed by the n th iteration, denoted $\mathrm{H}(n)$:

$$\mathrm{H}_n(0.q_1 q_2 \cdots q_n) = \begin{pmatrix} \mathrm{R}e \\ \mathrm{I}m \end{pmatrix} \sum_{j=1}^{n} \frac{1}{2^j} H_{q_0} H_{q_1} H_{q_2} \cdots H_{q_{n-1}} H_{q_j}$$

$$= \sum_{j=1}^{n} \frac{1}{2^j} (-1)^{e_{0j}} \operatorname{sgn}(q_j) \left(\frac{(1-d_j)q_j - 1}{1 - d_j q_j} \right) \tag{4}$$

$$\operatorname{sgn}(x) = \begin{cases} 1, & if \ x > 0 \\ 0, & x = 0 \end{cases} \tag{5}$$

$$e_{kj} = \#(\ k\text{"} \ preceding \ q_j) \bmod 2 \tag{6}$$

$$d_j = e_{0j} + e_{3j} \mod 2 \tag{7}$$

where $\mathrm{sgn}(x)$ is the sign function, # is the counting function, and $k \in \{0,3\}$. The exit point of each sub-square of the Hilbert curve coincides with the point of entry into the next sub-square.

Definition of a zigzag curve: In this paper, we study Reshape curves on images of size $H \times W$, assuming that both H and W are equal to 1 and are equally divided into 2^n parts, given a real number $t \in [0,1]$, which can be expressed in finite-length quadratic form: $t = 0.q_1 q_2 \cdots q_n$, with the symbol R defined as follows:

$$\mathrm{R} : 0.q_1 q_2 \cdots q_n \mapsto \begin{pmatrix} \left(\sum_{k=1}^{n} q_k 4^{n-k} \% 2^n \right) * \dfrac{1}{2^n} + \dfrac{1}{2^{n+1}} \\ \left\lfloor \dfrac{\sum_{k=1}^{n} q_k 4^{n-k}}{2} \right\rfloor * \dfrac{1}{2^n} + \dfrac{1}{2^{n+1}} \end{pmatrix} \tag{8}$$

Definition of the Piano curve: the generation process of the Piano curve is similar to that of the Hilbert curve. In this paper, we first denote the nth approximation of the Peano curve as $\mathrm{P}_n : t \in \mathrm{I} \to \mathrm{P}_n(t) \in \mathrm{Q}$, and the Peano curve is the limit of P_n when n tends to infinity. The binary to decimal conversion function is denoted by B, and the Peano curve is generated as follows:

$$\mathrm{P}_n \left(\frac{\mathrm{B}(q_1 q_2 \cdots q_n)}{2^n - 1} \right) = \begin{pmatrix} \dfrac{\mathrm{B}(q_1 q_3 \cdots q_n)}{2^{n/2}} \\ \dfrac{\mathrm{B}(q_2 q_4 \cdots q_{n-1})}{2^{n/2}} \end{pmatrix} \quad p \in \mathrm{Q} \tag{9}$$

$$\mathrm{P}_n(t) = p_0 * (1-s) + p_1 * s, \, t \in [\mathrm{P}_n^{-1}(p_0), \mathrm{P}_n^{-1}(p_1)] \tag{10}$$

where $s = \dfrac{t - \mathrm{P}_n^{-1}(p_0)}{\mathrm{P}_n^{-1}(p_1) - \mathrm{P}_n^{-1}(p_0)} \in [0,1]$, $q_i \in \{0,1\}$.

IV. Survey on the functional adaptation of community public space layout under the influence of theater culture

In the process of global urbanization, the break of historical lineage and the crisis of homogenization of public space have given rise to the urgent need for cultural translation. Theater, as the earliest narrative art form of mankind, its spatial archetype contains a unique mechanism for generating the spirit of place, and its cultural genes provide aesthetic references for spatial design that go beyond functionalism.

IV. A. Overview of the study area

In this study, a city street community A is selected as the empirical research object, and the transformation project of this area fully embodies the innovative application of theatrical culture in the reconstruction of community public space. The original texture of the site presents a spontaneous organic form, forming a multi-scale nested structure with the neighboring canal landscape zone. Based on the theory of fractal geometry, the research team deconstructs cultural elements such as the scroll pattern of Yueju Opera and the space-time narrative of Kunqu Opera through parametric technology, and constructs a fractal space grammar with theatrical tension.

In order to explore the functional appropriateness of the public space layout in Study Area A, this paper combines eye-tracking technology to conduct field research.

IV. B. Research on the Functional Adaptation of Community Public Space Layout

IV. B. 1) Interest statistics based on eye tracking

Eye movement technology can visualize the human visual trajectory by capturing human eye movements, such as eye hopping and the stay and movement of the gaze point, and determine the range of the visual perception area of the human for the test content as well as the range of the visual stay area of the test content, so as to infer the most appealing visual part of the human. Eye tracking technology based on digital eye movements is becoming

more mature, which utilizes a high-frequency sampling infrared camera device to capture real-time images of the user's eyeballs, and further acquires eye tracking data through image processing.

In this paper, the eye-tracking system is first deployed in study area A. Ten typical observation points are selected to record the visual search patterns of tourists in the fractal layout area. The data were collected through a 300-second free exploration task, focusing on the spatial coupling between gaze hotspots and fractal nodes. This eye-tracking experiment used the Tobii Pro Lab system for data analysis, and EXCEL was used to organize and analyze the data. Before performing the analysis, this paper excluded data content with sampling rate lower than 75% to ensure the accuracy of the experimental data. In the end, this paper obtained data from 965 valid tourists, including 625 females and 340 males, with a gender ratio of 1.8:1. The subjects were mainly between the ages of 10 and 40.

The eye movement data were analyzed using 2 eye movement data indicators, the average number of gaze points and the average gaze time, and the mean and standard deviation of each eye movement data are shown in Table 1. The mean number of gaze points reached 1093.36±31.93 and the mean gaze time was 126.32±5.58 s in observation point 6, which were the best performance in both data among the 10 observation points.

Table 1: Various eye movement data

Eye movement index	Observation point	M	SD	Eye movement index	Observation point	M/s	SD
Average fixation count	1	984.73	24.46	Average fixation duration	1	107.84	5.38
	2	917.35	23.72		2	103.22	4.78
	3	980.18	22.98		3	96.37	3.66
	4	1002.45	34.27		4	48.23	4.07
	5	997.17	23.22		5	56.91	3.12
	6	1093.36	31.93		6	126.32	5.58
	7	988.35	20.28		7	48.27	3.16
	8	1005.24	21.77		8	39.18	1.22
	9	972.28	23.62		9	63.23	2.48
	10	983.15	15.54		10	72.11	3.13

IV. B. 2) Research Results

Combined with the results of visitors' interest statistics, the questionnaire for evaluating the functional adaptation of public space layout in Study Area A was designed. The survey involves the design of questionnaires with a total of 30 questions in 5 parts: degree of accessibility, emotional perception, satisfaction with artistic expression, satisfaction with the type of public art, and satisfaction with cultural communication. This paper conducted a field survey in October 2024, a total of 511 questionnaires were issued, 500 valid questionnaires, the effective recovery rate of 97.85%. In order to ensure the objectivity of the survey research, this paper investigated different age, educational background and economic status groups to collect the real opinions of everyone.

The questionnaire was administered according to a Likert scale measure, setting each question item to five options: 1 means very dissatisfied, 2 means not very satisfied, 3 means fair, 4 means more satisfied, and 5 means very satisfied. The results of the comparison of the mean test scores for the five dimensions are shown in Figure 1. It can be seen that the Cultural Communication Satisfaction dimension has the highest score, with a mean of 3.91, and the five dimension score means are ranked from largest to smallest: Satisfaction with cultural communication > Emotional perception > Satisfaction with artistic expression > Satisfaction with type of public art > Degree of accessibility. The mean value of the five dimension scores exceeded 3.5, and overall tourists rated the functional suitability of the public space layout in Study Area A as high.
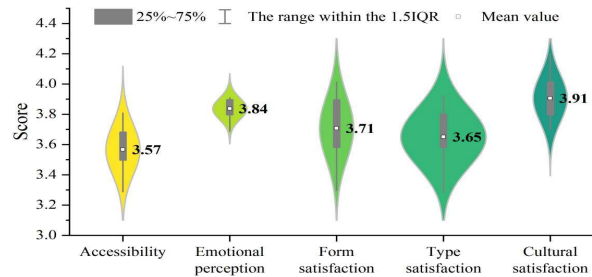

Figure 1: Mean test scores for the five dimensions

IV. C. Functional Fit Model Testing

The community public art function fitness model constructed in this paper has a total of 15 observational variables and 5 latent variables, the latent variables include accessibility, emotional perception, satisfaction with artistic expression, satisfaction with the type of public art, and satisfaction with cultural dissemination, and each latent variable corresponds to its own observational variable, i.e., factors affecting each latent variable. Accessibility includes three observational variables: geographic location, location of dense community traffic, and line-of-sight accessibility. Emotional perception includes three observational variables: interactive experience, comfortable and pleasant feeling, and artistic attractiveness. Satisfaction with artistic expression includes 3 variables: shape and scale, material and color, and light and shadow effects. Satisfaction with the type of public art includes 3 observational variables: interactive installation, art exhibition, and multimedia. Satisfaction with cultural dissemination includes 3 observational variables: theater culture dissemination, aesthetic education function, and city image display.

IV. C. 1) Credibility analysis

Reliability refers to the degree of stability or consistency of the measurements. Intrinsic reliability refers to whether a set of questions in a questionnaire measures the same concept. Extrinsic reliability refers to the degree of consistency of a questionnaire's results when measured at different times. Reliability analysis, also known as "reliability analysis," is used to test the consistency, reliability, and stability of a scale. The method usually used is Cronbach's alpha, and in general, if the reliability coefficient is over 0.9, it means that the reliability is very good. If it is between 0.8 and 0.9, then it means it is OK. If it is between 0.7 to 0.8, then it is good. If it is between 0.6 and 0.7, it is barely okay. If it is below 0.6, then it has to be revised. The results of the questionnaire reliability analysis are shown in Table 2, where the reliability of the observed variables is greater than 0.9, and the total reliability coefficient reaches 0.938, which indicates that the data have good reliability.

Table 2: Results of reliability analysis

Variable	The revised items are correlated with the total	Cronbach's α after deleting the item	Cronbach's α
Geographical location	0.783	0.932	0.938
Densely populated areas in the community	0.806	0.932	
Unobstructed visibility	0.772	0.935	
Interactive experience	0.819	0.934	
Comfortable and pleasant feeling	0.902	0.931	
Artistic appeal	0.836	0.933	
Shape and scale	0.795	0.934	
Material and color	0.882	0.935	
Light and shadow effect	0.814	0.936	
Interactive installations	0.837	0.933	
Art exhibitions	0.904	0.929	
Multimedia	0.831	0.931	
The dissemination of drama culture	0.909	0.928	
The function of aesthetic education	0.845	0.932	
The display of urban image	0.823	0.931	

IV. C. 2) Fitting analysis

The great likelihood method was applied to estimate the parameters of the structural model and the results of the model fitting analysis are shown in Table 3. The CMIN/DF value of the exploratory factor model for each variable in this paper is 3.309, the value of GFI is 0.802, the value of RMSEA is 0.123, the value of AGFI is 0.708, the value of NFI is 0.814, and the value of CFI is 0.796, and each fit index is not optimal, which indicates that the model matches the scale in general, and the model fit is average, and the model needs further Adjustment.

Table 3: Results of model fitting Analysis

Index	Evaluation index		Model value
	Acceptable	Good	
χ²/df	<3	1.0-2.0	1846.289/558≈3.309
GFI	[0.7,0.9]	>0.9	0.802

AGFI	[0.7,0.9]	>0.9	0.708
NFI	[0.7,0.9]	>0.9	0.814
PNFI	>0.5		0.673
CFI	[0.7,0.9]	>0.9	0.796
RMSEA	<0.08	<0.05	0.123

IV. C. 3) Model corrections

The model correction mainly looks at the MI value and t-value, if the MI value is high and the t-value is low, the parameter variables are added or deleted or the correlation between the variables is increased to improve the model fit. The preset model in this paper does not need to add or delete variables, so referring to the correction index MI value, the correlation of variables needs to be increased to improve the model fit. The correlation between the dimension of cultural communication satisfaction and functional fit is added, and the results of the model fitting analysis after correction are shown in Table 4. The CMIN/DF value of the modified model is 1<1.258<3, the value of GFI is 0.923>0.9, the RMSEA is 0.032<0.05, and the values of AGFI and NFI are greater than 0.9, and all the fitness indexes meet the requirements, which indicates that the model fits well.

Table 4: Results of the modified model fitting analysis

Index	Evaluation index		Model value
	Acceptable	Good	
χ^2/df	<3	1.0-2.0	627.539/499≈1.258
GFI	[0.7,0.9]	>0.9	0.923
AGFI	[0.7,0.9]	>0.9	0.911
NFI	[0.7,0.9]	>0.9	0.928
PNFI	>0.5		0.764
CFI	[0.7,0.9]	>0.9	0.932
RMSEA	<0.08	<0.05	0.032

V. Conclusion

This study verifies the empowering effect of theater culture on the artistic design of community public space through theoretical construction and empirical analysis.

Among the data of 965 valid visitors, the average number of gaze points of observation point 6 reached 1093.36±31.93, and the average gaze time was 126.32±5.58s, which showed the best performance of both data among the 10 observation points. The results of the questionnaire survey showed that the dimension of cultural communication satisfaction scored the highest, with a mean value of 3.91 points, and the mean values of the five dimensions in descending order were: cultural communication satisfaction>emotional perception>satisfaction with artistic expression>satisfaction with the type of public art>accessibility, with the mean value of the five dimensions exceeding 3.5 points, and the tourists overall had a high evaluation of the functional suitability of the layout of the public space of the study area A. The reliability of the observed variables was greater than 0.5 points, and the reliability of the observed variables was greater than 0.5 points, which is the highest among the 10 observation points. The reliability of the questionnaire observation variables is more than 0.9, and the total reliability coefficient reaches 0.938. The CMIN/DF value of the corrected model is 1<1.258<3, the value of GFI is 0.923>0.9, the RMSEA is 0.032<0.05, and the values of AGFI and NFI are all greater than 0.9, and the fitness indexes meet the requirements, which verifies the effect of expression of the theater culture elements in the community public art design.

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