# Analyzing the Geometric Distortions in a Chinese Scholar Garden in the Lin Family Mansion and Garden Using Computer-Simulated Projections

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**Abstract.** The geometric distortions to increase illusory spatial depth observed in Renaissance architecture were based on the theories and principles of perspective projection, and used by Renaissance architects to plan a layout in multiview drawings and transform them into a perspective drawing to foresee how the building would appear when built. The mathematical principle of linear perspective can thus explain the cause-and-effect relationship of geometric distortion in Renaissance architecture. As the drawing system did not completely develop into a design tool in Eastern China, applications of the theories and techniques of Chinese scholarly paintings in architectural designs are relatively unknown. In this study, a computational approach was utilized to model the perspective projection of distorted geometries for investigating the cause of the architectural distortions and their expected visual effects, as observed in the Lin Family Mansion and Garden. The results revealed that the distorted geometries were designed to create a pictorial presentation of elevation oblique views of architectural elements that blended into the landscape background to form a continuous scrolling painting, which unfolded in a panoramic view from the Octagonal Pavilion. Consequently, an effective computer-aided research technique was demonstrated to study classic architecture and discover an untold story of how architectural elements can be distorted, based on the oblique projection used in Chinese paintings, to create a three-dimensional representation.

**Keywords:** Computer-Aided Research, Chinese Scholar Garden, Lin Family Mansion and Garden, Geometric Distortion, Oblique Projection, Forced Perspective.
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## 1 INTRODUCTION

Architecture in the Renaissance sometimes exhibited unusual geometric distortions. These distortions were often related to a forced perspective that was used to create a specific perceptual effect for particular viewpoints. As illustrated in Figures 1(a) and 1(b), the apse of the Church of

San Satiro in Milan, Italy, was constructed with distorted geometries to create an exaggerated perception of depth for the view seen looking straight ahead upon entering [13].

In Colonnade Spada, located in Rome, Italy, as illustrated in Figures 1(c) and 1(d), a similar approach was employed. Not only were the architectural elements, e.g., columns, deliberately deformed, but each pair was constructed shorter and shorter, the farther it was from the entrance. The arrangements of these deformed architectural elements were also manipulated. The floor slopes upward and is shaped like a trapezoid. The spacing between each pair of columns is also gradually reduced, based on the desired perspective, looking toward the statue at the end of the colonnade. Together, these deliberate manipulations create a forced perspective that expands twofold the illusory spatial depth of this colonnade [1].

(a) (b) (c) (d)

**Figure 1**: Examples of geometric distortions based on forced perspective: (a) Apse of the Church of San Satiro, viewed from the front; (b) Apse of the Church of San Satiro, viewed from the side; (c) Colonnade Spada, viewed from the front; and (d) Colonnade Spada, viewed from the side.

Similar architectural geometric distortions can also be observed in the Chinese scholar garden of the Lin Family Mansion and Garden. Chinese scholar gardens refer to small-scale private gardens primarily located in the Suzhou area of China, built during the Ming Dynasty (1368–1644) and the Qing Dynasty (1616–1911). The gardens are so named because of the involvement in the design by scholars, who were also poets and painters, who desired to enrich the spatial experience within the limited physical settings [2],[7],[9].

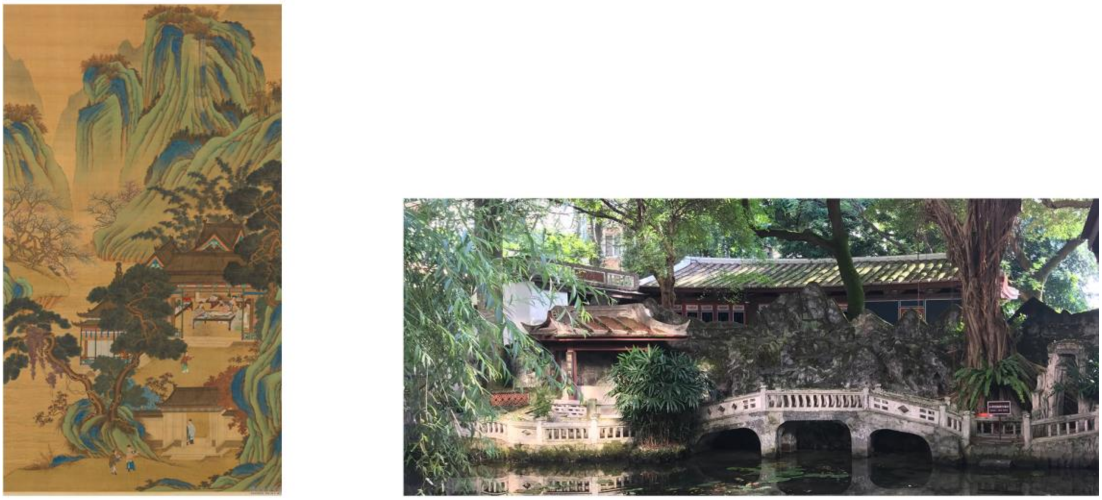
The Lin Family Mansion and Garden, located in Banqiao, Taiwan, is a classic example of a Chinese scholar garden preserved today. In this architectural complex, architectural constructions exhibit uncommon geometric distortions. Figure 2 illustrates different angles of view of a pavilion as part of the theatrical stage located in Fangjian Study, a place in the garden where scholars gathered. As illustrated, the pavilion presents uncommon distortions in perspectives viewed from the surrounding corridor, which is not perpendicular to its façade (Figures 2(a), 2(b), and 2(d)). This is because, instead of the expected rectangular form, the pavilion is constructed in the shape of a parallelogram. However, when viewed perpendicularly, as in Figure 2(c), the pavilion is presented from perspective that resembles an elevation oblique view.

An elevation oblique is a conceptual representation resulting from a parallel projection that displays a three-dimensional object in its true elevation, with a parallel line projecting backward at an angle to create the third dimension [3],[4]. This is the most employed pictorial form of three-dimensional objects in Chinese scholar paintings [4],[14]. Consequently, the pavilion, along with the rock mountain, reduced bridge size, and landscaping, forms a horizontal scroll painting from its expected viewpoint. Figure 3 shows a comparison of a typical Chinese landscape painting with an image of the entire setting of the Fanjiang theatrical stage captured using a wide-angle lens [11].

How people from a particular culture and time paint their three-dimensional worlds as two-dimensional art can influence how they construct their three-dimensional architectures to compose two-dimensional architectural scenes. This is evident in the geometric distortions, based on a forced linear perspective, observed in Renaissance architecture. Linear perspective refers to a mathematical method that can transform the geometries in orthographic plan and elevation views into a perspective view [3]. It is believed that the linear-perspective system was collectively established by many scholars who were both painters and architects through their two-dimensional art, three-dimensional architecture, and published text [4],[10]. As painters were involved in the architectural design, it is not surprising that the special visual effects created by the geometric distortions have a causal relationship with the theories and techniques employed in two-dimensional art.

(a) (b) (c) (d)

**Figure 2**: Oblique Pavilion viewed from different observation points: (a) from the right at the corridor, (b) from the right at the extended pavilion of Fangjian Study, (c) looking straight from the extended pavilion, and (d) from the left at the corridor.



(a) (b)

**Figure 3**: Comparison of the architecture in two-dimensional landscape painting with three-dimensional theatrical stage: (a) Hall of Treasured Paintings, by Qiu Ying (Ming Dynasty, collection of National Palace Museum, Taiwan), and (b) theatrical setting of Fangjian Study.

Chinese scholar gardens are known to have had a scholar who specialized in both painting and literature involved in their design and construction. A Chinese scholar garden, therefore, exhibits a pictorial idea found in a scholarly landscape painting and promotes expertise in "garden making [6],[15]." The Lin Family Mansion and Garden, built around 1890, is a typical Chinese scholar garden that embodies pictorial ideas in its spatial experience [5],[8]. As a result, it is reasonable to suspect that the geometric distortions of its architectural construction relate to a two-dimensional Chinese scholarly landscape painting.

In addition to the distorted pavilions in Fangjian Study, more geometrically distorted pavilions are scattered around the Banyan Shade Pond. In addition to the Triangular, Square, and Octagonal Pavilions, the Fishing, Oblique, and Overlapping Pavilions were constructed in parallelogram forms with three different angles, as shown in Figure 4. Along with the three pavilions with standard geometries of triangles, squares, and octagons, they exhibit different forms of uncommon geometric distortions that can be seen in the complex. Literature reviews thus far have attributed these variations as a method of adding diversity to the complex, leaving unknown their particular visual effects from particular viewpoints.

In this study, we propose that these distortions follow the concept of presenting a two-dimensional Chinese scholarly painting with the arrangement and distorted construction of three-dimensional objects for particular expected scenes. A Chinese scholarly painting depicts three-dimensional architectural elements with a pictorial system of elevation obliques of paraline drawing based on an oblique projection system. Therefore, this study proposes a computer-simulated projection to study the interrelationship of the geometrical distortions and the resultant visual presentation of two-dimensional framed scenes from expected viewpoints.


**Figure 4**: Pavilions with and without geometric distortions around Banyan Shade Pond.

## 2 METHOD

Linear perspective is a drafting method that can depict what we see based on what we know. The technical research question asked in this study essentially is whether the perspective view of an investigated architectural construction based on a perspective projection would appear as a parallel view based on parallel projection. Figure 5 illustrates the spatial relationship of the two-dimensional drafting of linear perspective with its depicted three-dimensional subject. A typical drawing method of linear perspective is laid out with a parallel projected side view and top view rotated with a preferred angle. By setting up a station point (SP) representing the observer on the top view, a horizon line (HL) representing eye level, and ground line (GL) representing the ground level on the side view, the vanishing points (VP) can be determined. The geometries of the subject in perspective can then be drafted with those VP following the principles of linear perspective on the front view as a picture plane (PP), as illustrated in Figure 5(a). Figure 5(b) shows that the setting of the top and side views in drafting using the principles of linear perspective are the direct parallel projections of the top and side views perpendicular to the subject unfolding at 90° to align with the front view. Figure 5(c) further depicts this with a point of observation according to the setting of linear perspective drafting. The lines connecting that observation point with the critical points where the geometric changes of the three-dimensional subject intersect the vertical picture plane. By connecting those intersection points, the resultant image is identical with the image drawn with the two-dimensional drawing method of linear perspective. In other words, the two-dimensional perspective drawing of a subject can be directly created with a three-dimensional perspective projection.

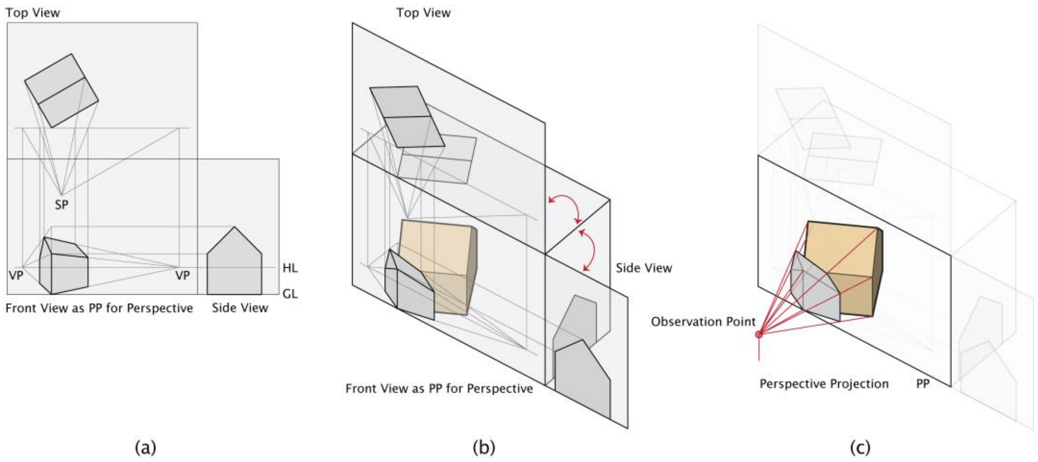
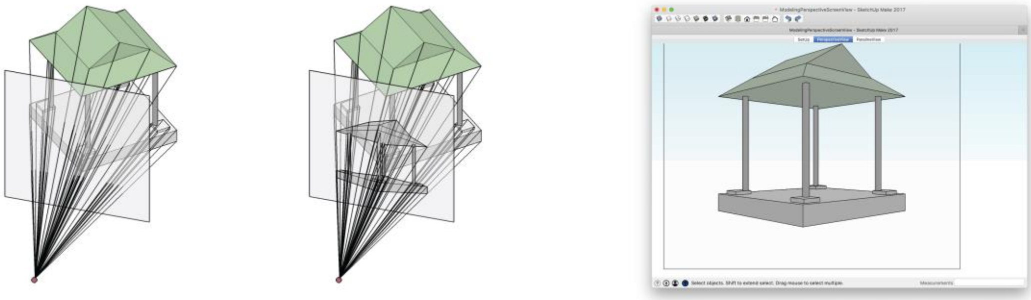



**Figure 5**: Perspective drafting, perspective projection, and parallel projections of orthographic and oblique projections.

Figures 6(a) and (b) illustrate the process of the three-dimensional computer-simulated perspective projection. The 3D model of the analyzed subject is constructed with the 3D modeling program of SketchUp [12]. As the name of the software implies, the modeling program SketchUp operates based on a concept that the user can draw on a 3D canvas to create a 3D model. It therefore provides tools one can relate to conventional drafting and thus makes it an ideal 3D modeling program for this study. As illustrated in Figure 6 (a) and (b), in addition to the architectural subject of a simplified Chinese style pavilion that can be found in the Lin Family garden, the location of the viewpoint and a vertical plane representing the picture plane are constructed according to the field study. Lines representing the rays of light projected from the critical corners of the subject (where geometries change) are connected to the viewpoint. Intersections of those projected lines on the modeled picture plane can then be connected into an image representing the perspective projection of the subject from that particular point of observation. Figure 6(c) further shows that, when set, a camera view from the red dot of the station point looking toward the pavilion, the drawn perspective image from the connected dots perfectly overlays with the 3D model in perspective from that view, attesting that the simulation of the three-dimensional perspective projection can be a faithful representation of the two-dimensional perspective drawing.

Figure 7(a) further shows the difference between parallel and perspective projection systems. Perspective projections converge to a single viewpoint, with the resulting parallel lines converging to a vanishing point, resembling an image of what we see on a picture plane. Meanwhile, parallel projections allow the parallel lines to remain parallel on the picture plane, resulting in a conceptual representation of what we know [3]. There are different variations of parallel projection. For example, orthographic projections are projected perpendicularly to the picture plane to create multiview plan and elevation drawings; oblique projections intersect the picture plane at an oblique angle, revealing third-dimensional information to create a three-dimensional paraline drawing. Figure 7(b) further illustrates that the perspective view from the blue dot looking toward the subject demonstrates significant discrepancy of the 3D model in this perspective view with the drawn image based on parallel projection.

These different approaches to describing three-dimensional geometry result in a fundamental difference between two-dimensional artistic representations in the West and East. By abandoning the vanishing point, a Chinese painting can also be free from a single viewpoint, resulting in an unlimited pictorial space that can be expanded horizontally, as far as the painter wants. A Chinese painting is thus presented in a scrolling form that is expected to be viewed section by section, instead of all at once. To this end, this computer-simulated projection study is conducted to examine if there is a particular pattern in the perspective projections of those geometrically distorted pavilions that would appear to be parallel projected pictorial forms as preferred by the Chinese painters.

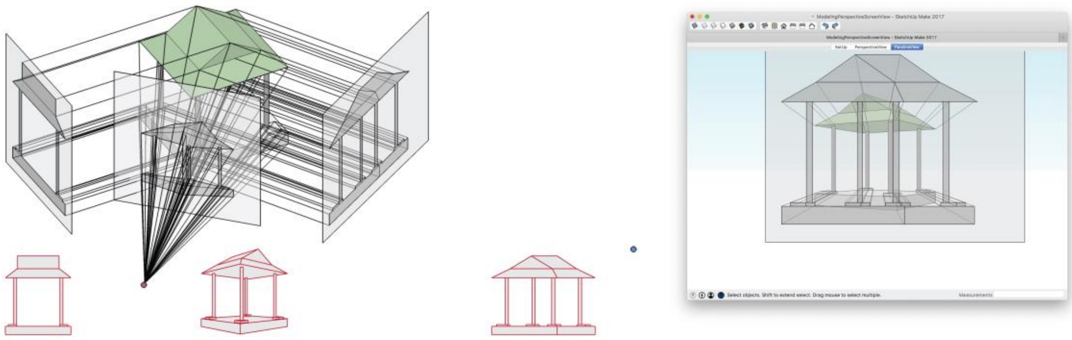


(a) (b) (c)

**Figure 6**: Process of computer-simulated perspective projection and analysis: (a) Modeling the architectural construction, as well as the perspective projection and picture plane, (b) drawing the perspective drawing on the picture plane by connecting the intersection points with projection lines, and (c) the drawn perspective overlays perfectly with the pavilion shown in perspective viewed from the station point.

## 3 STUDY WITH COMPUTER-SIMULATED PROJECTION

Yuan-Ye, a classical text authored by Ji Cheng, a famous garden maker and painter of the Ming Dynasty, well illustrates how the techniques of composing a Chinese scholarly painting can be applied to compose the three-dimensional scenes in a Chinese scholar garden [6]. As a result, exploring a Chinese scholar garden can invoke the viewing experience of a Chinese scholarly scroll painting.



(a) (b)

**Figure 7**: Difference of parallel and perspective projection: (a) Comparisons of the resultant images from parallel and perspective projections, and (b) the discrepancy exhibited by the image resulted from parallel projection with the pavilion viewed in perspective.

In light of this unique relationship between two-dimensional art and three-dimensional architecture, we hypothesize that the geometric distortions in the Lin Family Mansion and Garden are specifically manipulated to allow expected viewpoints to create scenes that resemble the three-dimensional pictorial architectural forms depicted in scroll paintings. To analyze these viewpoint relationships and the geometric distortions, we utilized computer-simulated projections to determine the proper viewpoint and observe how those distortions appear.

A pavilion, in Chinese, refers to a place to stop and stay; this implies that they provide opportunities to see the garden without blocking foot traffic. We thus viewed the garden from the different pavilions to examine how they appeared from the different viewpoints. The intention of the projection simulation is to reveal whether a viewed image resulting from a perspective projection will resemble the pictorial presentation of an oblique projection.

A 3D model of a portion of the Lin Family Mansion and Garden was constructed mainly based on first-hand on-site measurements. In addition to the physical setting of the garden and pavilions, the perspective projections from viewing all the other pavilions from each of the six pavilions around the pond were modeled based on the linear-perspective principle. We followed the procedures described in the Method Section (Section 2). The locations of viewpoints and direction were based on the on-site investigation where preferred views were available. Lines were drawn to connect the dot representing the viewpoint and points of the geometrical change of the pavilion. Intersections of those lines with the picture plane were connected to form an image representing the perspective drawing from that viewpoint looking at the pavilion. A total of 30 projection models were generated. Figure 8 illustrates those perspective projection models and resultant projected images on picture planes of the six pavilions from different viewpoints.

## 4 RESULTS AND ANALYSIS

Table 1 illustrates the cross-comparisons of perspective projections from all the possible viewings of the pavilions with images captured from the simulated perspective projections using a Canon EOS 5D Mark III equipped with a 50 mm lens. Several observations can be made:

The Triangular Pavilion can only be viewed clearly from the Octagonal pavilion, owing to its distant location and the obstructions caused by the tree landscaping (Table 1: column F, row 5). Similarly, only the Octagonal Pavilion can be viewed clearly from the Triangular Pavilion (Table 1: column E, row 6).

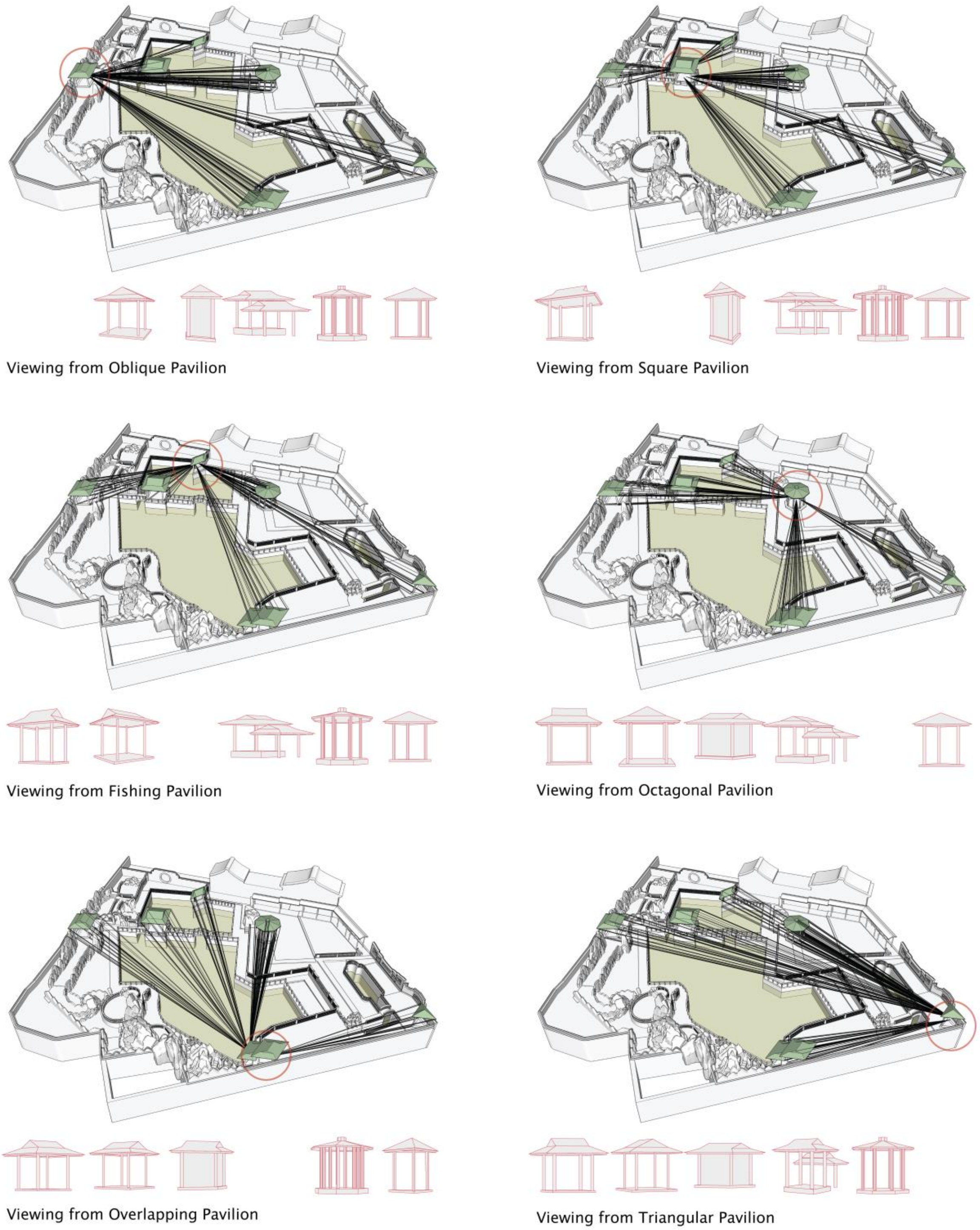



**Figure 8**: Computer simulation of the perspective projections of each pavilion from viewpoints in each pavilion around the Banyan Shade Pond.

However, the Square and Overlapping Pavilions can be partially viewed from a slightly different viewpoint in the Triangular Pavilion to avoid the landscape obstructions (Table 1: column B, row 6; column D, row 6). However, the views from the Triangular Pavilion do not appear to engage the overall landscaping of the Banyan Shade Pond.

The Square and Oblique Pavilions are similar in their size and form. They are located close to each other and thus have similar perspective projections in the viewings of other pavilions. The Oblique Pavilion is only distorted with a small angle of 12°. In many cases, it does not display noticeable distortions in perspective projections from other pavilions (Table 1: column A). However, the slightly distorted angle allows it to be aligned to the line-of-sight viewing from the Octagonal Pavilion, making its projected image closely resemble an elevation view (Table 1: column A, row 5).

The Fishing Pavilion has the most distorted geometries. The examination of its perspective projections from the other pavilions shows that the distorted form appears awkwardly from most of the viewpoints but has a perfect elevation oblique view to the Octagonal and Triangular Pavilions (Table 1: column C, row 5 and 6). However, when viewing the Fishing Pavilion from the Triangular Pavilion, it appears considerably smaller owing to the distance and is blocked by the Octagonal Pavilion (Table 1: column C, row 6). Therefore, it can be considered that the extremely distorted form of the Fishing Pavilion was deliberately arranged for viewing from the Octagonal Pavilion.

Another distorted pavilion, the Overlapping Pavilion, also presents a perfect elevation oblique view to the line-of-sight from the Octagonal Pavilion (Table 1: column D, row 5). It also appears to be an elevation oblique view to the Fishing and Square Pavilions (Table 1: column D, rows 3 and 2). As these two pavilions are located close to each other, the perspective projection would be similar, considering the Overlapping Pavilion is located significantly farther from those three pavilions. Because the Overlapping Pavilion is located at the corner around the pond, it cannot be seen from all directions, the chance it would be seen in an awkwardly distorted perspective is relatively limited compared with the Fishing Pavilion.

The evaluation of the perspective projections, shown in Table 1, across the viewing from the Octagonal Pavilion reveals that the other five pavilions are all presented in a pictorial form of parallel projections to it (Table 1: row 5). The Triangular, Square, and Oblique Pavilions are present in elevation views of the multiview drawing, whereas, the Fishing and Overlapping Pavilions are present in elevation oblique views of the paraline drawing system. In addition, the octagonal form factor allows it to be seen in a similar way from the other five pavilions as demonstrated from its presented projections examined vertically in column E of Table 1.

In addition to the perspective projection analysis, the location and formal configuration of the Octagonal Pavilion suggest that it was designed as the best place to view the garden in its entirety, as it offers a panoramic view. The distorted Fishing, Oblique, and Overlapping Pavilions are connected with mountains, rockery walls, water, tall and small trees, as well as flowers to form a continuing landscape, just like a scroll painting. Figure 9 illustrates a collage of images where each is taken perpendicular to one of the vertical sides of the octagon. Framed by the columns, the series of those five photos forms a continually panoramic view in which the distorted and undistorted pavilions are all presented in elevation or elevation oblique views. This illustration confirms our hypothesis that the geometric distortions are specifically manipulated for a particular viewpoint. In our study, the expected viewpoints are located in the Octagonal Pavilion, where the distorted geometries are presented in a pictorial form of paraline drawing that is commonly used in Chinese scholarly paintings.

## 5 CONCLUSIONS

The cause-and-effect relationship of how the geometries are configured in a conceptual representation of plan and elevation would appear in perspective has been well-established with the principle of linear perspective.

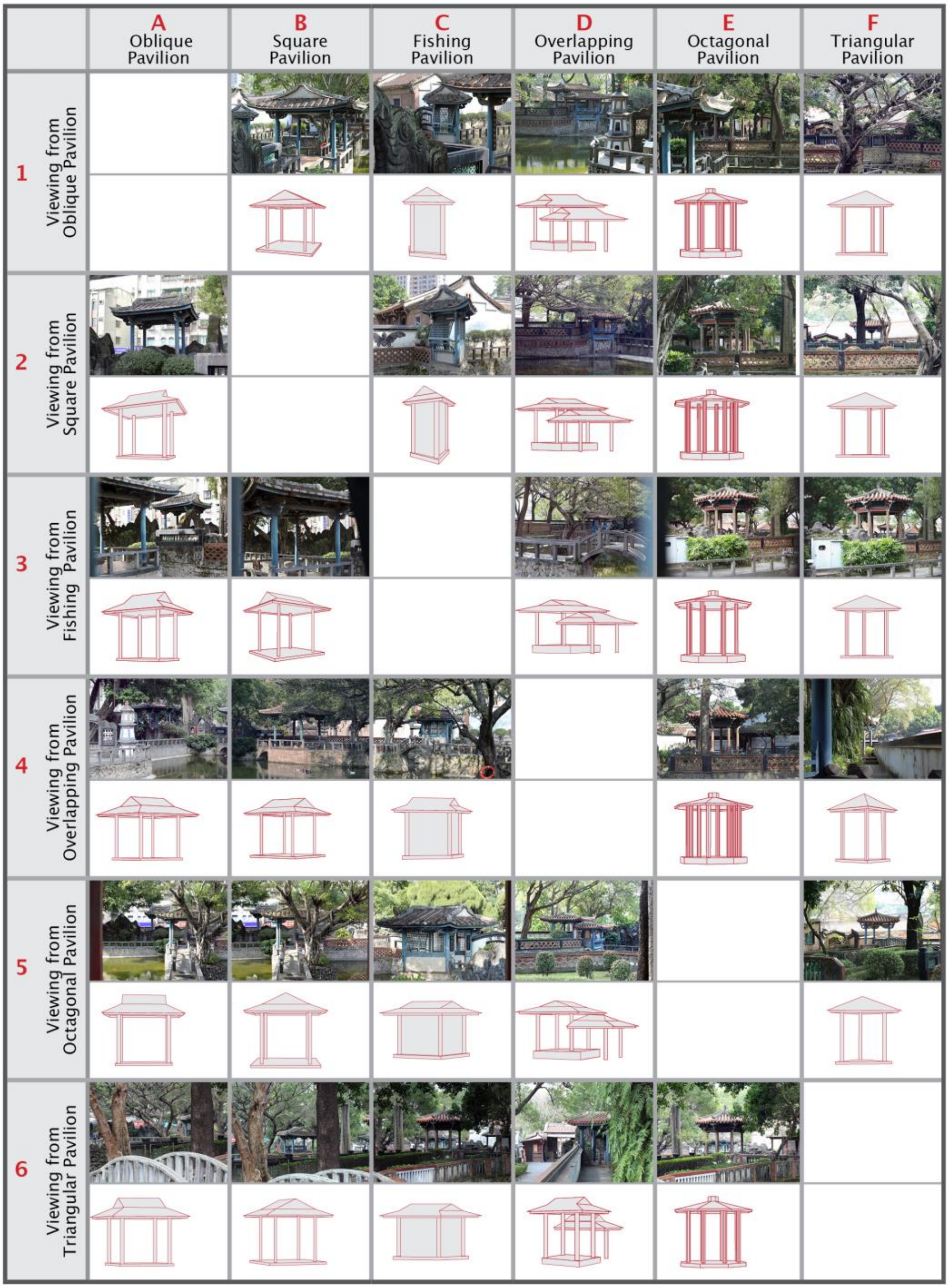



**Table 1**: Cross comparisons of perspective projections along with on-site photos from pavilion to pavilion.

**Figure 9**: Panoramic collage of views from the Octagonal Pavilion.

As a result, the same relationship can be used in reverse to distort the architectural geometries to create a particular visual effect for an expected viewpoint. Several examples that are observed in Renaissance architecture attest to this application from their two-dimensional art to three-dimensional architecture. Although the drawing system did not develop into a systematic design tool in Eastern China, the applications of the theories and techniques in Chinese scholarly paintings in architectural designs cannot be ignored. The Chinese scholar garden, which is known for the involvement of a painter in the process of garden design, is one of the most notable.

In this study, a computer-simulated perspective projection was utilized to investigate the cause of the architectural distortions and their undocumented intended visual effects, as observed in the Lin Family Mansion and Garden, a Chinese scholar garden preserved in Taiwan. The results of comprehensive cross-comparisons and analysis of how each pavilion would appear in the perspective projection from each pavilion reveal that the landscape and architectural elements around the Banyan Shade Pond closely resemble a Chinese landscape scroll painting, which unfolds horizontally, centered around the Octagonal Pavilion. Viewing from the Octagonal Pavilion, through one scene after another framed by columns, the distorted geometries appear to be a pictorial presentation of elevation or elevation oblique views of architectural elements that blend into the landscape background to form a continuous scrolling painting, which unfolds in a panoramic view.

Although this study presents a visual demonstration of how a three-dimensional geometrical distortion can be particularly manipulated for a two-dimensional framed view of a preferred point of view based on theories and principles of Chinese landscape painting, whether it can be concluded as a method of design as the linear perspective employed by Renaissance architects to distort the geometrical arrangement to create illusory spatial depth remains to be seen. More cases exhibiting similar strategies are required. However, this study does validate a practical method and principle for such investigation.

In summary, an interdisciplinary research design was demonstrated in this study for effectively applying a computer-aided research technique to interpretive-historical research. By constructing the digital model of the investigated cultural heritage gardens, the geometrical configuration can be isolated from the contextual information that might not be the original design intent. This model enables the simulation of the perspective projections to examine the visual perception of the pavilions based on Chinese scroll painting techniques, thereby, establishing a believable interpretation of how architectural elements can be distorted, based on the oblique projection used in Chinese paintings, to create a three-dimensional landscape painting.

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