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Towards a Practical Method for Voxel-based Visibility Analysis with Point Cloud Data for Landscape Architects: Jichang Garden (Wuxi, China) as an Example

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Abstract: This paper focuses on GIS-based visibility analysis to explore landscape architecture compositions as a means to understand visual-spatial characteristics and identify related design principles. More specifically, the paper elaborates a practical method to employ high-resolution data acquired by terrestrial LiDAR (Light Detection and Ranging or Laser Imaging Detection and Ranging) for this purpose. Though LiDAR provides a powerful means to digitally capture the real-world, methods like GIS-based visual landscape research that utilize viewshed analysis ideally require a continuous Digital Landscape Model conduct visibility computation. Therefore, one of the obstacles before the visual analysis is to process the points into surface or solid models. Voxel-based algorithms are powerful means to process LiDAR data. There are many applications known of voxel-based visibility analysis but requires often specialist software that is hard to handle or unavailable to landscape architects in practice. This paper showcases an attempt to use standard software for voxel-based visibility analysis. It presents a practical method for applications in landscape architecture analysis. Jichang Garden (Wuxi, China) is used as an example. The historical garden is an evocative example of a landscape architecture composition that displays skilful applications of spatial-visual design principles and therefore worthy of analyse.

Keywords: LiDAR, voxel-based visibility analysis, Jichang Garden, landscape architecture, visual landscape research

1 Introduction

Visual landscape research is a research field important for the advancement of landscape architecture (NIJHUIS et al. 2011). In visual landscape research, GIS-based visibility analysis is a significant strand of research (for example FORD et al. 1959, WILSON et al. 2008, GOODCHILD et al. 1990, LLOBERA 2003). As visibility computation aims to understand the visual connection between landscape and human perception, accurate visibility computation requires detailed visual environment data. Air born and terrestrial LiDAR (Light Detection and Ranging or Laser Imaging Detection and Ranging) are powerful means to acquire high-resolution data landscapes throughout the scales. LiDAR is a technique that can capture high-resolution 3D data of objects' surface rapidly and cost-effectively by targeting an object with a laser and measuring the time for the reflected light to return to the receiver (YU et al. 2010, WU et al. 2016, GARGOUM & BASYOUNY 2019). There is a wide range of applications of LiDAR in landscape research to study landscapes and interpret cultural features (WITHARANA et al. 2018), for archaeological landscape analysis (HARMON et al. 2006), combined with social media to quantify the visual-sensory landscape qualities (VAN BERKEL et al. 2018), visualization of the Kyoto gardens (GIROT et al. 2017), etc. As for the visibility

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analysis method based on the point cloud, hidden point removal HPR (KATZ et al. 2007) can avoid creating a surface from the point applied for the visibility analysis, but this method is hardly applicable for the noisy or non-uniformly sampled point cloud. Though LiDAR techniques provide many potentials for digitally capturing the real-world, digital scenarios like GIS-based visual landscape research utilizing viewshed analysis require a continuous digital landscape model surface to conduct the computation.

Therefore, one of the obstacles before the visual analysis is to process the points to surface or solid models. To translate point clouds into surface or solid models three different approaches can be used to conduct the visibility analysis with LiDAR data: 1) voxel-based, 2) ray-tracing, and 3) surfaced-based approaches (ALSADIK et al. 2014). Voxel-based techniques are mainly applied for volumetric data applications. Though computing the visibility with voxels is less accurate, it is an efficient method to automatically generate a solid model for GIS-based visual analysis (HINKS et al. 2013). Using voxels to calculate visibility can avoid generating a triangulated mesh surface that might be expensive and time-consuming (ALSADIKA et al. 2013). Several researchers, such as Yi Zhao, proposed a method to voxelize the point cloud data and compute the 3D visibility of Shanghai streets' environment with the voxels (ZHAO et al. 2020). However, voxel-based visibility analysis often requires specialist software that is hard to handle or unavailable to landscape architects in practice. Moreover, most of the research focused on the development of the voxelization methods instead of the applications in visual landscape research. Especially when the research focus is on understanding the spatial-visual organization and design principles of landscape architecture compositions there is a strong need to develop practical GIS-based visibility approaches to enable landscape architecture researchers to exploit the powerful computational possibilities that standard GIS-software like ArcGIS offers (NIJHUIS 2011, NIJHUIS 2016).

Fig. 1: (a) Master plan of the Jichang Garden; (b) Typical scenery of Jichang Garden

This paper focuses on GIS-based visibility analysis to explore landscape architecture compositions as a means to understand visual-spatial characteristics and identify related design principles. More specifically the paper elaborates a practical method to employ high-resolution data acquired by terrestrial LiDAR for this purpose. This paper showcases an attempt to use standard software for voxel-based visibility analysis and presents a practical method for applications in landscape architecture analysis. Jichang Garden, a traditional Chinese private garden in Wuxi (China) is used as an example (Fig. 1). The historical garden is an evocative example of a landscape architecture composition that displays skilful applications of spatial-visual design principles (STUART 1990, JIANG & WANG 2006, DONG 2014) and therefore worthwhile to analyse by means of GIS-based visibility computation. The spatial composition of the garden was already subject to research from many perspectives, and includes the interpretation of contemporary texts, records, poems, and paintings (STURMAN 1993, PAN et al. 2012, SHU et al. 2018). By doing so important insights were acquired, but digital augmented spatial analysis is not performed until now.

2 Voxel-based Visibility Analysis Method

The proposed practical method aims to establish the bridge between the raw point cloud data and GIS-based visual-spatial analysis. Therefore, the workflow consists of three parts: (a) collecting the point cloud from the real environment, (b) transferring point cloud to voxelized models, and (c) conducting GIS-based visual-spatial analysis with the voxels (Fig. 2).

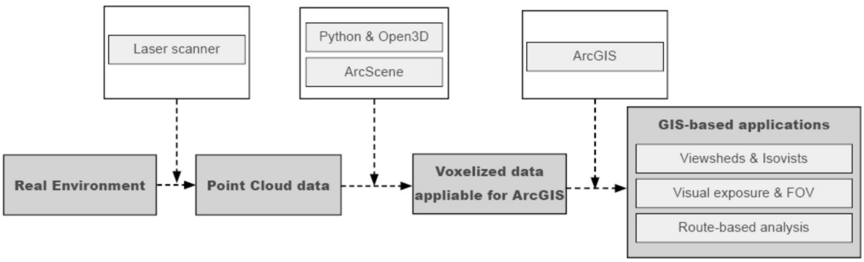

Fig. 2: The workflow

2.1 Scanning Point Cloud Data of Jichang Garden

The scanning works have been conducted in two days (19^{th} and 20^{th} in March 2021). The point cloud is acquired in two different ways. First by true colour 3D-point cloud data acquisition with a Trimble X7 Scanner by still scanning. This process takes 3-5 minutes for each scanning point (the distance between adjacent two measuring points is around 10 meter). True colour data have only been collected in the main parts of the garden, around the pools. Secondly data has been collected by a ZEB-Horizon scanner. The scanner was handed by one walking person, and the point-cloud data would be scanned by tracking the surroundings, offering complementary data. By integrating the two types of data a complete point cloud of Jichang garden was constructed (Fig. 3).

2.2 Voxelization for the Point Cloud

After the construction of the point cloud the data was voxelized (Fig. 4). The process consisted of the following steps: (a) Using Python and Open3D to read the point cloud data; (b) setting the size (length of cube's edges) for the voxels according to the purpose of the computation; (c) griding the point cloud data with Open3D; (d) extracting the coordinate data for each voxel's central point as "pts" format; (e) using Arcscene to read "pts" file and loading the central points' coordinate data; (f) modelling each voxel with the central point's coordi-

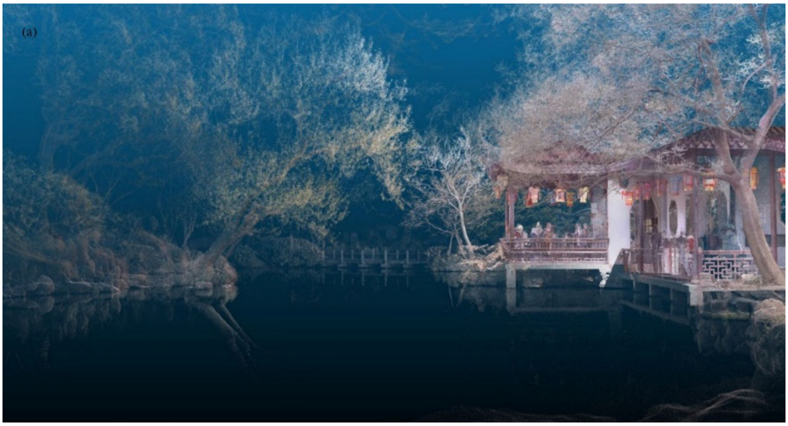

Fig. 3: Visualization of the point cloud data showing a typical scene in the Jichang Garden

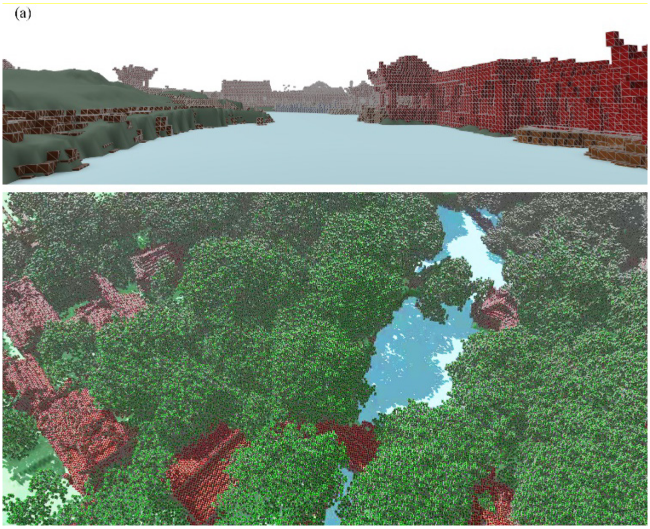

Fig. 4: Voxelized LiDAR data of Jichang Garden, a) Buildings b) Vegetation

nate and the length of the edges; (g) finalizing the voxelization for the point cloud data, and forming a digital model as “multipatch” format, which can be used in ArcGIS.

2.3 Visibility Analysis with Voxels

After the voxelization, the visibility analysis can be done. In this process, several steps are needed, including: (a) setting points on the surface(s) of the targets, which are used to depict the targeted surface(s); in this case, the pools in the garden have been selected as targets for visibility analysis; therefore, the points are set with a grid of 0.5m*0.5m on the pools’ surfaces; (b) computing the visibility of the targeted objective(s) with accumulative viewsheds method.

3 Visual-spatial Analysis of Jichang Garden

As a historical garden that has survived for more than 400 years, different garden owners have conducted many modifications and reconstructions from different periods. One of the most critical modifications was completed in 1668 by a celebrated gardener named Zhang Shi and the garden's owner Qin Songling (HUANG 2011). The resulting spatial structure and the related buildings, routes, and rocks still determine the appearance of the garden as visible today. To get a grip on the design intentions of Zhang, many texts, such as gardening literature written by Zhang and Qin, poets, and essays by Qin's friends and other visitors, are also available. A few of them exposed Zhang's gardening works' design intentions and principles, by means of visual-spatial layouts. For example, one of Zhang's design intentions is to assemble functional buildings on the east, while the natural landscape elements like hills, woods, rocks, and water bodies are on the west. In this way, important sites and main buildings are directly and indirectly connected to the central pool. Thus the pool is an important organizing element in the composition of the garden.

In order to reveal the central role of the pool in the composition three aspects are explored by means of voxel-based analysis: (a) organising the views of the garden with the central pool, (b) in-position viewing analysis, which reveals the visions from fixed viewpoints, and sites for observers to stay still and view the sceneries, and (c) analysing in-motion viewing in the garden, which showcases how observers' vision would be shifted from place to place when walking in the garden along the routes.

3.1 Organising Views with the Central Pool

To investigate the precise visual characteristics the potential visibility of the pools' surface was computed (Fig. 5a). As the map shows, the gradient of colours is applied, in which the highest visibility is shown in red and the lowest in green. For example, notice how the Zhuguangxie building is highlighted red, which means the viewpoints around this building could view almost 60% of the pool's surface. The possibility of being visible to the surrounding terrains has been visualized for the pools' surface. With the application of interpolation, a colour gradient is used to illustrate the potential to be seen. The high possibility areas are shown in red and the lower in blue (Fig. 5b). As the analysis indicates two core areas of the pools, having a higher possibility to be viewed, can be identified. These zones in the pool play an important role in the spatial-visual composition of the garden.

The visibility map shows that the pool's viewsheds cover the pathways, important sites, and prominent buildings. Therefore, observers' field of view (FOV) would include the pool when sightseeing in the garden. Looking at the raster map for the probability of being seen, we also notice that the central areas of the pool have a relatively high possibility of being viewed. As a result, the water body is the garden's central feature that organises the views. In addition, the gardener shaped the pool as "8" on the master plan with one peninsula, known as Hebutan, and one building known as Zhiyujian (Fig. 7a). In this way, the designer created two central open areas with the pool as the main focal point and, at the same time, the connecting factor. The viewpoints around the water body provide for a variety of (framed) views that offer many different perspectives on the lake and the vegetation and build structures that are part of the landscape architecture composition. As a result, the garden is perceived as much bigger than it is.

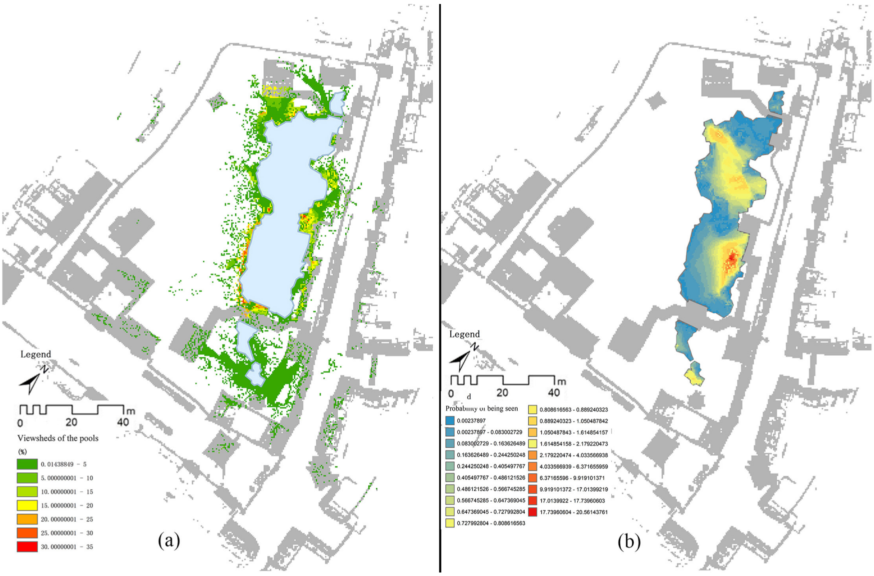

Fig. 5: (a) Viewsheds of the pools; (b) Probability of being seen for the pools' surfaces

3.2 In-position Viewing of the Jichang Garden

According to the computation, we find that several sites have wide-ranged visions on the pool, including the viewpoints at Zhuguangxie, Zhiyujian, Hebutan, and Jiashutang (Fig. 7b). Taking Zhiyujian as an example, many clues indicate that Zhang's layout intentionally put this building to a location surrounded by water by three sides. From the very beginning, Zhiyujian had been initially built as a building on a bridge crossing the pool (Fig. 6a), but later, Zhang removed the structures on the pool away and exposed the pool's panorama directly to Zhiyujian (Fig. 6b). In addition, the poem from Qin's friend, Wu, also demonstrated that the

Fig. 6: Comparison of the views at Zhiyujian: (a) Landscape painting of original Zhiyujian building, by Song Maogong, *Landscape Painting for Jichang Garden*, Ming Dynasty; (b) Landscape painting of the modified Zhiyujian, by Qin Zhihao's copies from Wang Jiang's paintings, Qing Dynasty; (c) Contemporary view at Zhiyujian

design intention is to guarantee observers to view the pool from a higher position. The evidence for the other three sites is also easy to access; we can conclude that these locations are precisely selected and designed so that the observers could have extensive views of the pool in these locations.

3.3 In-motion Viewing of the Jichang Garden

In addition, the spatial relationships between the routes and the pool are also interesting (Fig. 7c): three different pathways are involved in the discussion, including (c) the path-1 on the east, which is beside the pool, (b) the path-2 on the west, which is close to the pool, and (c) the path-3 on the west, which is relatively far away from the pool. Path-1 is a pathway mainly covered by a winding porch. Different species of vegetation with various height levels (such as trees, bushes, flowers, etc.) and many rocks were set next to it. Consequently, the visions from path-1 to the pool vary from place to place, showcased by the computed raster visibility map. We noticed that the visibility of the pool for several corners of the porch is lower than other locations, which were intentionally designed by shielding the views with vegetation and rocks. Equivalently, several sites were arranged to have wide-ranged on the pool, which

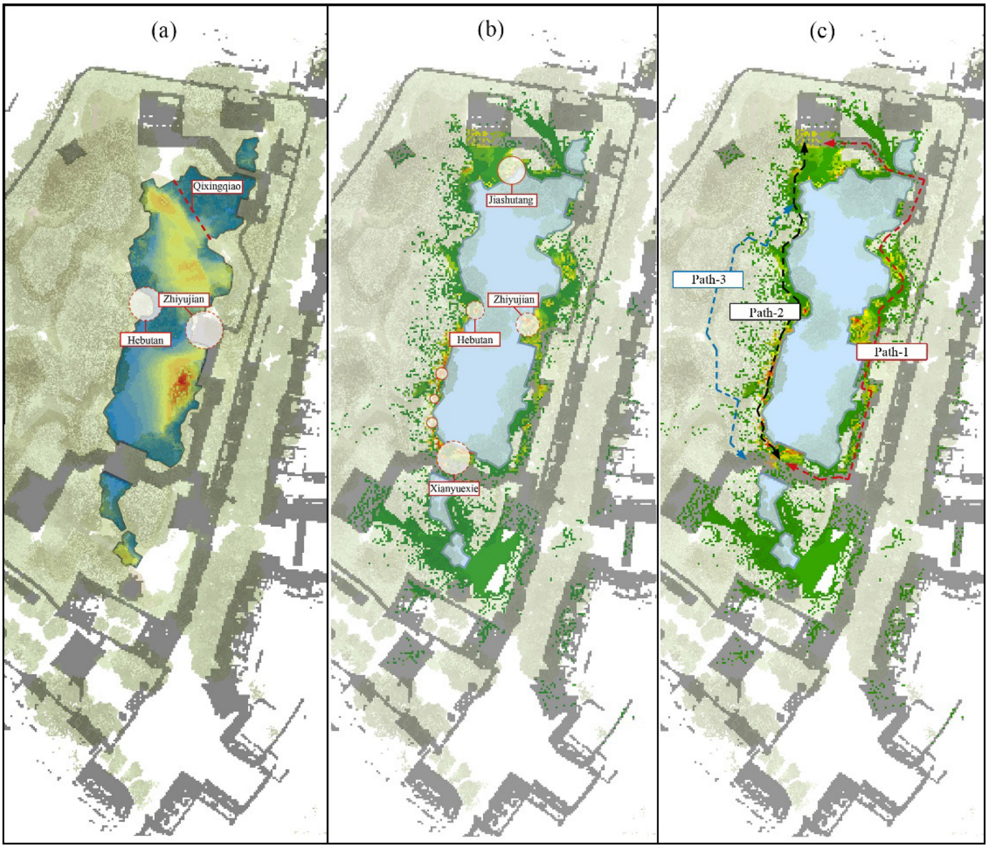

Fig. 7: (a) Three different paths around the pools; (b) Good viewpoints to view the pool, such as Xianyuexie; (c) Shaping the pool as "8" on the master plan with one peninsula

was carefully designed to lead views to the pool. As a result, visitors' visual perceptual experiences would be poetic due to the rhythms of shifting visual-spatial arrangements when walking on this path. Path-2 and path-3 are two parallel paths set on the west of the pools. Path-2 is close to the pool, and only several trees higher than eye level were planted between the path and the pool. As a result, path-2 has quite open visions of the pool, also shown on the visibility map. Path-3 is located to the west of path-2. Rocks, hills, and woods were arranged to block path-3's views to the pool; thus, only several specific locations on this path could view the pool. Though the two pathways are adjacent, the designer used this visual-spatial arrangement to create two different perceptual experiences for the routes to enhance sightseeing's entertainment.

4 In Conclusion

Modelling high-precision digital models or using the dense point cloud data to conduct visibility analysis is usually expensive and time-consuming in terms of the computation process. For example, the raw scanning point cloud for the Jichang Garden is dense (over 3,000,000 points for a random cube of 10m*10m*10m), making the visibility computation hardly possible with regular computers. Therefore, it is necessary to develop methods to simplify these huge and detailed point clouds and balance the computation's efficiency and accuracy. In this process the points from vegetation, rocks, and buildings are simplified as solid voxels with the consequence that lifelike details have been replaced by cubes. Consequently, sacrifices of details to promote the efficiency and accessibility for computation are needed and influence the accuracy of the analysis outcomes and their interpretation. Though the flaw exists regarding the computing efficiency and accessibility, the presented method is relatively accurate in acquiring the visual characteristics and accessible to be utilized in design analysis and visual-spatial research.

In conclusion, this paper proposed a method to utilize point cloud data by voxelizing points and conducting visibility analysis with the computed voxels. In addition, we applied this method to calculate the visibility of the pools in Jichang Garden. The potentials of this method on visual-spatial analysis have also been explored in this garden. Several conclusions can be drawn from the visual-spatial analysis, including (a) the pool's function as the visual focus organises the visions of the garden; (b) shaping the pool as "8" makes the pool have two central open areas, which enhances the depth of views for the garden; (c) several sites were delicately designed to have wide-ranged visions on the pool; (d) visual-spatial characteristics for the pathways around the pool are much varied to enhance the perceptual experience's entertainment in the garden.

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