Planning and Design of Modern Municipal Scenery Statue Based on Collaborative 3D Virtual Reconstruction Design

Chen Qu[1*]

[1] School of Art and Design, Anhui Business and Technology College, Hefei 230041, China

Corresponding author: Chen Qu, qchen82115@163.com

Abstract. The planning and design of modern municipal scenery statues are crucial elements in urban landscapes, contributing to cities' cultural identity and aesthetic appeal. In recent years, the integration of 3D virtual reconstruction techniques has emerged as a powerful tool in preserving, interpreting, and enhancing municipal statues. This paper explores the application of 3D virtual reconstruction in the planning and design of modern municipal scenery statues, aiming to elucidate its benefits, challenges, and implications for urban design practices. Through a comprehensive review of existing literature, case studies, and methodologies, this research investigates the process of 3D virtual reconstruction, including data collection, modeling, and visualization techniques. Practical considerations for implementing virtual reconstruction in municipal statute projects, such as cost, time, and technical expertise, are discussed, along with an evaluation of its effectiveness in enhancing the planning and design process. The paper also identifies opportunities for future research and advancements in the field of virtual reconstruction for urban landscapes, highlighting the potential for innovation and collaboration in the sustainable management of cultural heritage. Ultimately, this study aims to contribute to a deeper understanding of the role of 3D virtual reconstruction in shaping the built environment and preserving the cultural heritage of modern cities.

Keywords: 3D Virtual Reconstruction; Collaborative CAD; municipal scenery statue;
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1 INTRODUCTION

Municipal scenery statues stand as silent sentinels, imbuing urban landscapes with historical narratives, cultural symbolism, and aesthetic charm. From towering monuments commemorating national heroes to quaint sculptures adorning neighborhood parks, these statues play a pivotal role in shaping the identity and character of cities around the world. As enduring symbols of civic pride and heritage, municipal scenery statues serve as focal points for community engagement, public gatherings, and collective memory, enriching the urban experience for residents and visitors alike [1-3].

In recent years, the field of statue planning and design has witnessed a paradigm shift with the advent of 3D virtual reconstruction technologies. These digital tools offer unprecedented capabilities for visualizing, analyzing, and simulating municipal scenery statues in virtual environments. By digitizing physical forms into intricate 3D models, virtual reconstruction enables designers, planners, and stakeholders to explore new design concepts, assess spatial relationships, and anticipate the visual impact of proposed statues within the urban fabric [4-6]. The integration of 3D virtual reconstruction into modern statue planning and design holds immense promise for enhancing the creative process, streamlining decision-making, and fostering greater public engagement. By harnessing the power of digital visualization, planners can transcend traditional constraints of scale and scope, envisioning statues in their full glory and detail before they ever take physical form. Moreover, virtual reconstruction offers opportunities to integrate historical data, cultural context, and environmental considerations into the design process, ensuring that new statues harmonize with their surroundings and resonate with local communities. In light of these advancements, this research seeks to investigate the planning and design of modern municipal scenery statues through the lens of 3D virtual reconstruction. By examining the intersection of technology and tradition, this study aims to elucidate the potential benefits, challenges, and implications of integrating virtual reconstruction into statute projects [7]. Through empirical analysis, case studies, and critical reflection, this paper endeavors to contribute to a deeper understanding of how virtual reconstruction can enrich the urban landscape, inspire creative expression, and promote cultural heritage preservation.

The objectives of this research are as follows:

1. To explore the role of municipal scenery statues in urban landscapes and their significance in shaping the identity of cities.

2. To examine the principles and practices of 3D virtual reconstruction and its application to modern statue planning and design.

3. To assess the impact of virtual reconstruction on the creative process, decision-making, and stakeholder engagement in statute projects.

4. To develop design guidelines and recommendations for incorporating 3D virtual reconstruction into the broader framework of urban planning and design.

2 RELATED WORK

Municipal scenery statues have been integral to urban landscapes for centuries, serving multifaceted roles beyond mere ornamentation. Scholars such as Jackson (2019) have highlighted the historical significance of statues as markers of cultural identity and historical memory within urban settings [8]. These statues often commemorate significant events, individuals, or ideals, functioning as tangible expressions of civic pride and collective heritage [9]. Moreover, municipal scenery statues contribute to the spatial organization of cities, serving as landmarks, waypoints, and focal points for navigation and wayfinding [10]. In the realm of urban planning and design, statues play a crucial role in shaping the visual character and spatial organization of urban environments. They contribute to the creation of memorable public spaces, fostering a sense of place and identity that enhances the quality of life for residents and visitors alike [11]. Furthermore, statues serve as catalysts for social interaction and community engagement, providing opportunities for public gatherings, cultural events, and civic rituals [12]. While the historical significance and urban planning role of municipal scenery statues are well-documented, there remains a need for further exploration of their potential in contemporary urban contexts. Rapid urbanization, globalization, and socio-cultural changes have transformed the dynamics of urban life, necessitating new approaches to statute planning and design that respond to the evolving needs and aspirations of diverse communities [13].

The emergence of 3D virtual reconstruction technologies has revolutionized the fields of cultural heritage preservation, architectural design, and urban planning. These techniques enable the creation of digital replicas of physical objects and environments with unprecedented accuracy and detail, opening up new avenues for visualization, analysis, and interpretation [14]. In the realm of cultural heritage preservation, 3D virtual reconstruction has emerged as a powerful tool for documenting, restoring, and presenting historic monuments and artifacts [15]. By digitizing cultural heritage assets into immersive 3D models, virtual reconstruction facilitates remote access, conservation, and education, ensuring the preservation of tangible and intangible heritage for future generations [16]. Similarly, 3D virtual reconstruction techniques have revolutionized the architectural design process, enabling architects and designers to visualize and simulate complex spatial configurations with greater precision and efficiency [17]. Virtual reconstruction tools allow for iterative design exploration, rapid prototyping, and collaborative decision-making, leading to the development of innovative and sustainable architectural solutions [18].

Despite the advancements in 3D virtual reconstruction technologies and their widespread adoption in various fields, there exists a notable gap in the literature regarding their integration into modern statue planning and design practices. While studies have explored the application of virtual reconstruction in cultural heritage preservation and architectural design, limited attention has been paid to its potential impact on the planning and design of municipal scenery statues. Specifically, there is a need for research that examines the feasibility, efficacy, and implications of incorporating 3D virtual reconstruction techniques into the statue planning process. Key questions remain unanswered regarding the integration of virtual reconstruction with existing design methodologies, stakeholder engagement practices, and regulatory frameworks. Furthermore, there is a lack of empirical evidence on the practical challenges, opportunities, and outcomes associated with the use of virtual reconstruction in statue projects, particularly in real-world urban contexts.

Addressing these gaps in the literature is crucial for advancing our understanding of how 3D virtual reconstruction can enhance the planning and design of municipal scenery statues, contribute to the creation of vibrant and inclusive urban environments, and preserve cultural heritage for future generations.

3 METHODOLOGY

3D reality modeling technology is a combination of geographic mapping technology, Lidar remote sensing technology, video splicing fusion technology, 3D GIs technology, and other technologies through the scene reproduction and three-dimensional means of the combination of a new technology belonging to the security technology. 3D reality modeling technology can process photos and convert them into different forms of 3D models, such as point cloud data, 2D data, 3D data, plane images, etc. Different data source acquisition methods will affect the accuracy and application of the final 3D model [19]. According to different data sources, modeling methods can be roughly divided into three types. Based on traditional surveying and mapping data, laser scanning, and aerial photogrammetry.

3.1 Three-Dimensional Modeling Based on Laser Scanning

Laser point cloud can obtain data quickly and accurately and can obtain the depth of buildings, which is an effective data source for urban 3D real-scene modeling. Laser point clouds are divided into aerial point clouds and ground point clouds, but both have defects. Ground point clouds can not get information on the top of high-rise buildings, and information can be lost when there are trees or other obstructions on both sides of the road. The aerial point cloud can accurately obtain the three-dimensional information on the top of the high-altitude building, but the information on the bottom of the building or the part blocked by trees will inevitably be missing, which cannot meet the requirements of high precision.

3.2 Three-Dimensional Modeling Based on Aerial Photogrammetry

Aerial photogrammetry provides three essential types of data for digital cities: Digital pre-drawing (DLG), digital elevation model (DEM), and digital orthographic image (DOM). However, model texture information is missing when the complex building structure or other buildings and trees are obstructed. Analytical aerial triangulation refers to the work of solving the ground coordinates and external azimuth elements at the photo contact points by using the coordinates of image points, a few ground control points, and their external azimuth elements in an area. At present, the most commonly used method of aerial triangulation is the beam method, whose basic idea is to take each photo as a unit, list the error equation according to the principle of collinearity of photographic center, image point, and ground point, and solve the external azimuthing elements and specific point coordinates of each photo through iterative operations [201]. The schematic diagram of beam aerial triangulation is shown in Figure 1.

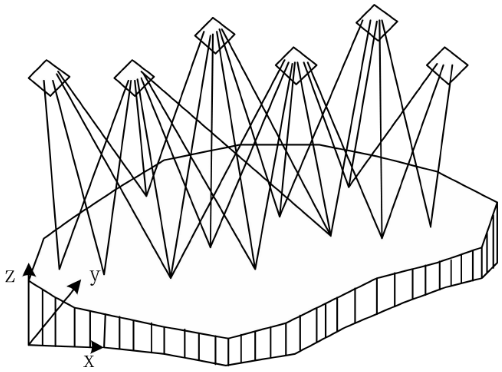

Figure 1: Schematic diagram of aerial triangulation by beam method.

The mathematical model of beam method adjustment is a collinear equation.

$$x = -f\frac{a_1(X-X_s)+b_1(Y-Y_s)+c_1(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)} \tag{1}$$

$$y = -f\frac{a_2(X-X_s)+b_2(Y-Y_s)+c_2(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)} \tag{2}$$

The error equation is obtained by expanding the collinear equation based on the Taylor formula in order to obtain the external azimuth elements of the photograph.

$$V = [A \quad B]_{\binom{t}{X}-L} \tag{3}$$

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \end{pmatrix} \tag{4}$$

$$B = \begin{pmatrix} -a_{11} & -a_{12} & -a_{13} \\ -a_{21} & -a_{22} & -a_{23} \end{pmatrix} \quad (5)$$

$$t = [dX_W \quad dY_W \quad dZ_W \quad d\varphi \quad d\omega \quad d\kappa]^T \quad (6)$$

$$X = [dX \quad dY \quad dZ]^T \quad (7)$$

$$L = \begin{pmatrix} l_x \\ l_y \end{pmatrix} \quad (8)$$

A and B are the coefficient matrices, which can be obtained by using the formula to calculate and solve the elements in the external orientation, and t and X are the correction numbers of the external orientation elements and point coordinates, respectively. The normal equation is:

$$\begin{bmatrix} A^T A & A^T B \\ B^T A & B^T B \end{bmatrix} \begin{bmatrix} t \\ X \end{bmatrix} = \begin{bmatrix} A^T L \\ B^T L \end{bmatrix} \quad (9)$$

3.3 Working Principle of Vehicle Laser Scanning System

When the vehicle laser scanning system conducts data acquisition, the data collected by various sensors on the platform is mainly centralized and unified under the GPS time system. The specific process is as follows: In the process of platform driving, the laser scanner scans the transmitted and received laser beam and records the Angle and distance between the scanning point and the scanner center. Differential GPS is used to record the geodetic coordinates of the vehicle in real time. At the same time, IMU records the vehicle's attitude Angle, such as direction Angle, roll Angle, and pitch Angle. The camera shoots the landscape image of the ground object at the set frequency during the journey, superimposes the coordinate rotation of the laser point and the geodetic coordinate system of the vehicle laser scanner according to the IMU attitude Angle, and finally obtains the coordinate value of the target point in the geodetic coordinate system. Based on the original data, such as geodetic coordinates, track line information, odometer data, scanning Angle, and scanning distance obtained by the vehicle system, a laser scanning system coordinate system based on the scanning vehicle is established. The coordinate origin is located at the laser beam emission, the Z axis is located in the vertical scanning plane of the instrument, and the X axis is located in the horizontal scanning plane of the instrument and is perpendicular to the Z axis. The Y-axis is located in the transverse scanning plane of the instrument and is perpendicular to the X-axis, and together with the X-axis and Y-axis, it forms the right-handed coordinate system, as shown in Figure 2.

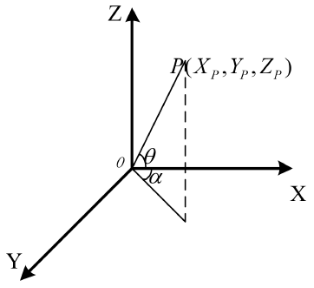

Figure 2: Laser scanning system coordinate system.

3.4 Multi-View Stereo Vision Algorithm Based on Depth Map

As shown in Figure 3, the dense reconstructed overall network structure based on depth map is mainly divided into two stages. The first stage is the multi-scale feature extraction module, which adopts the feature extraction network to extract the multi-scale features of the input image. The second stage is the cascaded adaptive view aggregation module, which aggregates the feature maps from different perspectives and then predicts the depth maps from coarse to fine. The main framework of the overall network structure is based on the improvement of the three-level CasMVSNet. In the multi-scale feature extraction module, a reference image and a number of other images associated with the reference image and their corresponding camera parameters are first input. After all images are input into the feature extraction network, each image will get a feature map with three resolutions. After obtaining multi-scale feature maps, the cascaded adaptive view aggregation module generates high-resolution depth maps from coarse to fine. Firstly, monograph transformation is used to map the lowest resolution feature maps under different viewing angles to the perspective of the reference image, and then VA-Net in VA-Net is used to adaptively aggregate the mapped feature maps to obtain the cost volume. The cost volume is regularized by 3DUNet used in MVSNet, and the lowest resolution depth map is estimated. Then, the low-resolution depth map is used to optimize the generation process of the high-resolution depth map, and finally, the depth map with the same resolution as the input image is generated.

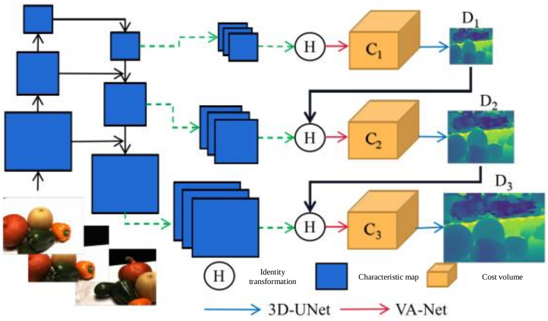

Figure 3: Dense reconstructed network structure based on depth map.

In this paper, a cascade method is used to predict the depth map, so features of different scales need to be extracted to form the feature pyramid. At present, there are two commonly used methods. One method is to adopt a lightweight feature extraction network, which is characterized by a simple network structure and can only generate a single-resolution feature map. Using this kind of network, it is necessary to scale the original image to different resolutions when input and let the feature extraction network extract the features of different resolutions respectively so as to obtain the multi-scale feature map. And the network parameters are shared when extracting the original image features with different resolutions. Another method is to use FPN. The characteristic of this kind of network is that it only needs to input the original image of one size to output the feature map of different scales, but it only uses the traditional CNN. In Cas-MVSNet, FPN is used to extract features, and the network structure of FPN is shown in Figure 4.

A transposed convolution module is in the network structure. The input of this module is two feature maps with different resolutions. The transposed convolution is used to up-sample the low-resolution feature maps and then stack them with the high-resolution feature maps along the channel direction and finally through a convolutional module. Since FPN combines feature information of different resolutions in the process of feature extraction and does not need to scale the input image, it only needs to input a high-resolution image to obtain multi-scale features. Therefore, this paper uses FPN to extract multi-scale features of images.

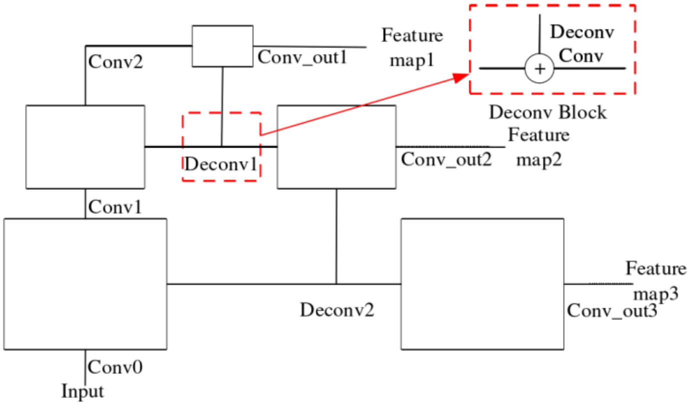

Figure 4: Network structure of the FPN.

4 PRECISION ANALYSIS OF 3D RECONSTRUCTION SCULPTURE MODEL

The accuracy analysis of a three-dimensional reconstructed sculpture model includes measurement accuracy, model integrity, correctness, authenticity, geometric structure, texture quality, etc. Based on the experimental results, this paper analyzes the accuracy of the monomer three-dimensional building model from two aspects: texture accuracy of geometric structure and position accuracy. The texture accuracy of the geometric structure includes whether the effect, tone and light and shadow relationship of the model are consistent. The integrity, correctness, coordination of texture data, map resolution, size, and consistency with the tilt model; Complete and correct data topological relationships of different types and levels of detail; The structure and texture quality of the model were evaluated by visual discrimination. Position accuracy includes plane position and elevation position. By calculating the difference in X, Y and Z directions between the coordinates of the 3D model of feature points and the actual coordinates, as well as the error in plane and the error in elevation, the accuracy of position accuracy can meet the accuracy index of the 3D reality model of the sculpture. Statistical Results of 3D Model Accuracy are shown in Table 1.

No.	Error /m			
	△ X	△ Y	horizontal	vertical
1	0.078	0.015	0.178	-0.023
2	0.076	0.021	0.045	0217
3	0.089	0.132	0.063	-0.018
4	0.102	-0.075	0.106	0213
5	-0.056	0.098	0.121	0.149
6	-0.064	0.105	0.098	0.068
7	0.023	0.026	0.124	0234
8	0.034	0.203	-0.015	0.147
9	-0.059	0.189	0.156	0.165
10	0.083	0.141	0.115	-0.088
11	0.096	0.147	0.135	0.094
12	0.108	-0.029	0.128	0204
13	0.167	-0.038	0.156	0.143
14	0.035	0.104	-0.077	0.115

15	0.046	0.114	-0.048	0.147
16	-0.078	0.147	0.175	0.038
17	0.168	-0.138	0.148	0.121
18	0.149	0.238	-0.028	-0.037
19	0.039	0.109	0.109	0.126
20	-0.029	0.049	0.137	0.146

Table 1: Statistical results of 3D model accuracy.

In order to verify the applicability of the proposed algorithm, four input images with different resolutions, 288×384, 576×800, 864×1152 and 1184×1600, were used in this section for experiments on the DTU data set. The experimental results are shown in Table 2. It can be seen from the experimental results that as the resolution of the input image increases, the errors in the accuracy of both the proposed method -FPN and the proposed method -FPN-X decrease. However, in terms of integrity error, the error of the proposed method -FPN and the proposed method -FPN-X at the input image resolution of 1184×1600 is higher than the error of the input image resolution of 576×800 and 864×1152. From the comprehensive performance point of view, the two methods have the best performance when the input image resolution is 864×1152, followed by the input image resolution is 1184×1600 and 576×800, and the input image resolution is 288×384 when the worst performance. Since the resolution of the input image used in the training stage is 512×640, the overall performance of the algorithm is good when the input image resolution is greater than 512×640, and the algorithm is poor when the input image resolution is less than 512×640. Therefore, the algorithm presented in this paper can be applied to scenes with input image resolution greater than 512×640.

Algorithm	Input resolution	Accuracy (mm)	Integrity (mm)	Overall performance (mm)
Method of this paper	(288,384)	0.761	0.543	0.652
	(576,800)	0.418	0.316	0.367
	(864,1152)	0.371	0.294	0.333
	(1184,1600)	0.330	0.360	0.345
Method of this paper -X	(288,384)	0.749	0.523	0.636
	(576,800)	0.423	0.314	0.369
	(864,1152)	0.372	0.302	0.337
	(1184,1600)	0.329	0.359	0.344

Table 2: Reconstruction results with different resolutions.

5 Opportunities for Future Research

Enhancing Data Acquisition Techniques: Future research efforts can focus on advancing data acquisition techniques for virtual reconstruction, including the development of new sensors, imaging technologies, and data processing algorithms to improve the accuracy, efficiency, and scalability of data capture. Integrating Augmented Reality (AR) and Virtual Reality (VR): AR and VR technologies offer immersive and interactive experiences for exploring virtual reconstructions in real-world environments. Future research can explore the integration of AR and VR into municipal statue projects to enhance public engagement, education, and cultural tourism. Addressing Ethical and Cultural Considerations: Future research should address ethical and cultural considerations related to virtual reconstruction, including issues of data privacy, intellectual property rights, and representation. Collaborative approaches involving stakeholders from diverse backgrounds can ensure that virtual reconstructions are ethically and culturally sensitive. Evaluating Long-Term Impacts: Long-term monitoring and evaluation of virtual reconstruction projects are essential to assess their impact on urban landscapes, cultural heritage, and community well-being. Future research can explore methodologies for evaluating the long-term effectiveness and sustainability of virtual reconstruction initiatives.

6 CONCLUSIONS

The planning and design of a modern municipal scenery statue, enriched through 3D virtual reconstruction and the integration of 2D and 3D images, is a multifaceted process that requires a careful balance of creativity, technical expertise, and community engagement. This comprehensive approach ensures an aesthetically pleasing and culturally relevant piece and a harmonious integration within the urban environment. The implementation and evaluation of 3D virtual reconstruction in municipal statute projects require careful consideration of practical factors such as cost, time, and technical expertise. While virtual reconstruction offers opportunities to enhance the planning and design process through improved accuracy, fidelity, and stakeholder satisfaction, ongoing research, and advancements are needed to address challenges and seize opportunities for innovation in the field. By leveraging emerging technologies and collaborative approaches, virtual reconstruction can play a transformative role in shaping urban landscapes, preserving cultural heritage, and fostering inclusive and sustainable development for future generations.

Chen Qu, https://orcid.org/0009-0000-3911-2091

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