



The Integration of Digital Technology and Traditional Craftsmanship: Innovative Practices in Contemporary Urban Sculpture

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SUMMARY: *The utilization of 3D digital technology in urban sculptures has led to the development of modern urban sculptures. With the constant developments in computer technology, the combination presents a broad scope of exploration, with a wide array of applications. This paper details the process involved in combining 3D digital technology in the making of urban sculptures, presenting two methods geared towards attaining an organic integration of the two technologies. Processing point cloud acquisition scanning algorithms, determining robotic scanning step distances, and preprocessing point cloud data information. Applying gradient calculation methods to the process of decomposing feature points for restructuring the edge contours of the point images of sculptures. Applying the Sigma model to the continuous 3D point cloud reconstruction of sparse point images and developing an automatic 3D reconstruction algorithm for sparse point clouds of sculptures. Analyzing the time complexity of the automatic 3D reconstruction algorithm and its application in the reconstruction of the urban volcano sculpture. This technique can extract point cloud data constrained by features from coffee cup models, plant pot models, gear models, and Einstein head busts, capture important features, and complete the 3D reconstruction of the urban volcano sculpture.*

KEYWORDS: *gradient operations; sparse images; 3D point cloud reconstruction; urban sculptures*

1 Introduction

With the technological development since the 1980s and the rapid rise of the internet era, social structures and lifestyles have been dramatically changed. People living in cities are beginning to require higher levels of urban space environment construction and cultural facilities. The combination of these two factors has driven the continuous development of urban sculpture art [1-3]. Its main functions include beautifying and improving the urban space environment, enhancing people's spiritual life, raising the level of public aesthetics, educating the masses, and concretizing and diversifying the city image [4, 5]. The statue named "Eight Women Throwing Themselves into the River," located in Mudanjiang City of Heilongjiang Province, reflects the deep respect of the author for the eight heroic women. The urban sculptures can be defined as large-sized installations. In case of reproduction of such monuments, the traditional artistry method depends upon physical molds to communicate artist's idea to the spectators. Even though the material used for making these molds is cheap in price, due to several reasons including intricacy in process, weight, and decoration policy, the reproduction process turns out to be complicated and tedious. This process inadvertently results in higher costs due to certain

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drawbacks [6-10].

With the quick changes in technology revolution, digital technologies born in the digital era are transforming various fields. Especially in recent times, with the increasing demand for urban ecological environment and cultural space by urban people, digital technology cannot be overlooked for the purpose of changing traditional sculptural craftsmanship [11, 12]. As there is a quick development in urban sculpture, the change in aesthetics arises from the interaction of traditional mentality and digital technology in creation. Traditional sculptural language and techniques increasingly struggle to articulate people's complex aesthetic experiences, while urban sculpture demands higher standards in form and aesthetic expression. The artistic aspirations and emotional expressions of urban sculpture continually seek new forms of manifestation. Digital technology has triggered a shift in aesthetic consciousness and approaches, leading to evolving aesthetic concepts among the public [13-17]. The integration of digital technology into urban sculpture creation reveals the mutually influential relationship between technology and artistic design, innovating traditional craftsmanship and art [18, 19]. Therefore, how to organically integrate digital technology with traditional urban sculpture craftsmanship is a question many artists are vigorously exploring.

Yang (2022) utilized image segmentation processing technology based on genetic algorithms to enhance the precision and production efficiency of sculptural works within a 3D-technology-based traditional sculpture creation platform [20]. Yu (2023) developed an urban sculpture art image design model integrating computer software, pattern texture computation methods, and intelligent sensor network technology. This model achieves an average pattern design time of 0.42 seconds and a resolution of 7200 pixels [21]. Sun (2025) employed Geographic Information System (GIS) technology to analyze the impact of topography, landforms, and climate on the design and layout of urban landscape sculptures, demonstrating a 45% potential enhancement in aesthetic design. The study recommended adopting green building techniques to design low-carbon, eco-friendly sculptures, thereby reducing maintenance costs. 3D modeling and Virtual Reality (VR) technologies visualize the design process and improve traditional design efficiency [22]. Advances in 3D printing technology have revolutionized the craftsmanship of artworks. Yu (2020) applied computer-designed sculpture models based on 3D printing technology, innovating the crafting process through a format of target data input and physical output [23]. Trento et al. (2024) integrated ground-penetrating radar, laser scanning, VR, parametric modeling, and numerical simulation to design a more efficient collaborative approach for stakeholders in creating large-scale sculptures in public spaces, thereby enhancing overall creative efficiency [24].

Duan et al. (2024) enhanced color and detail in generated sculptures by reinforcing color and texture loss learning during deep learning-based neural network training. They conducted aesthetic evaluations under total variation loss and applied this approach to public art sculpture design, elevating sculptural aesthetics [25]. Liu and Li (2024) employed a 3D weighted architecture estimation model to characterize urban sculpture images, describing sculptural attributes. By integrating deep learning for stylistic and period classification alongside similarity analysis of these features, they provided support for historical sculpture analysis, urban cultural heritage preservation, and urban planning [26]. Wan (2025) constructed a 3D sculpture-architecture estimation model. Generative Adversarial Networks (GANs), Convolutional Neural Networks (CNNs), and lightweight deep neural networks respectively performed image adjustment, feature extraction, and classification to enhance image accuracy. This led to the development of 3D statue construction technology in the field of pattern design for urban sculpture [27]. Guo & Wang (2021) developed a contactless measurement method based on depth-of-field 3D, an information system for steppers with motor control and image information capture ability, and the process of polygon construction of sculpture based on CAD

technology. This technology revolutionized the spatial conception of sculptural art, offering help to artists in their conceptualization and designing of artworks [28]. Liu & Guo (2023) applied multi-channel CNNs and LSTM networks to feature extraction, such as patterns, cultures, forms, and time-series associations from traditional sculptures. Based on computer-aided technology and CAD, they restored traditional sculptures [29].

In this article, the evolution path of modern urban sculpture is explored, and the conceptual difference between modern and ancient urban sculptures is discussed. Through the comparison of traditional sculpture making process and digital sculpture making process, the difference between the two is pointed out. In addition, the disadvantages of digital sculpture are presented, and the importance of applying 3D digital technology to urban sculptures is explained. This paper provides a creative process for the integration of digital technology and traditional craftsmanship. Point cloud scanning acquisition algorithms and preprocessing are analyzed. From the feature extraction of sparse point cloud images of sculptures, the optimization design of automatic point cloud 3D reconstruction algorithm for sculptures is optimized.

2 Urban Sculpture in Different Artistic Techniques

2.1 Forms and Development of Contemporary Urban Sculpture

(1) The development of modern urban sculptures can be classified into three groups [30]:

First, since urban sculptures relate to public areas, some changes have been made to their shape and art conception.

Second, there have been some transformations in terms of space and language in urban sculptures.

Third, there have also been changes in their production systems, management structures, and methods of promotion.

(2) Modern urban sculptures are starting to merge with traditional sculptures and show an obvious modern trend in terms of concept.

The development of modern urban sculpture in terms of its idea can be illustrated through the interpretation of spatial structure. The spatial structure in conventional sculptures was mainly understood as that of the sculpture. In modern urban sculpture, however, this idea is broadened into not only the spatial structure of the sculpture but also the space around the sculpture as well as its way of being exhibited and observed by people.

Modern urban sculpture interprets the spatial structure as an integrated body of the sculpture's physical structure, its exhibition space, and the way it is observed by people. In this sense, this interpretation of spatial structure differs significantly from that in conventional sculptures.

(3) The Contemporary Nature of Urban Sculpture

In the creation of urban sculpture through media art, the impact not only stems from the experimental consciousness of modern society but also from the limitation of the display venues of the work, which is closely related to the selection of material, thereby contributing significantly to the contemporary nature of the work. The emergence of this trend can be traced to the requirements of modern society, especially modern science, such as materials science, optics, and communications. Furthermore, the creation of modern urban sculptures uses computer simulation technologies. By using the computer, parameters like space, light, and material can be programmed into the software for visual simulation. The result can be continually modified based on actual need until the most appropriate solution can be found.

As they form their formal language, the current sculptures in cities deliberately exclude any narrative theme or irrelevant representation language that may have no bearing on the

contemporary significance. On the other hand, they use abstract forms of presentation that generalize and amplify the ideas.

To conclude, from several decades of growth, urban sculptures have demonstrated varied creative trends during various epochs. Influenced by the demands of contemporary urban cultural spaces and modern media, it emphasizes organic interaction within the overall spatial context, ultimately manifesting a distinct contemporary identity in its use of media.

2.2 Traditional Production Processes and Digital Sculpture Creation Processes

Sculpture can be categorized into traditional sculpture and digital sculpture.

The creation process for traditional sculpture: The sculptor first creates a small-scale clay model, then scales it up to a life-size clay sculpture several meters tall. A mold is cast to produce a life-size wax or resin model, followed by shell construction, casting, and installation.

Digital sculpture further divides into semi-digital and fully digital creation processes. The semi-digital workflow also begins with the sculptor creating a small clay model. This is then scanned in 3D or digitally modeled, shaped using 3D software until completion. The digital file is sent to a CNC sculpture factory to be machined into a foam sculpture several meters tall (which can be produced in sections). Finally, the process involves shell construction, casting, and installation.

Pure digital creation involves sculptors directly using digital sculpting software to create the sculpture data. This data is then sent to a CNC sculpture factory or 3D printing company to produce the physical sculpture.

Digital sculpture technology utilizes digital tools for sculptural creation and design, encompassing computer graphics, virtual reality (VR), augmented reality (AR), 3D printing, and other technologies. The main feature of computer sculpture is that the sculptural shapes created by computer have very high accuracy and complexity of structure. Computer sculpture gives freedom from physical limitations when constructing, changing, or restoring sculptures, since these activities can take place in the space of the virtual world. The presentation of computer sculpture takes place with the help of virtual reality technologies, which give the opportunity to see the multidimensionality of the sculpture.

2.3 Differences Between Traditional Sculpture and Digital Sculpture

The differentiation between traditional and digital sculpture is that the former involves using traditional substances such as clay and equipment in making large scale sculptures. This is a lengthy process involving many adjustments and occupying much space. However, digital sculpting does not require scaling up, uses less space, and requires less time and effort. It makes creation without clay or tools possible while allowing for modification and preservation.

Traditionally, an artist would have experienced numerous problems in trying to create complicated structures, however accurate he measured, carved, and polished his sculptures. In incorporating digital technologies in sculpturing, the artist is enabled to enter all the necessary information into the 3D modeling program for the best results in a shorter period of time. Through the use of advanced technical features, complicated structures and adjustments cannot be made without the help of computerized programs. Through this technique, 360 degrees and perfect creation becomes attainable.

2.4 Analysis of the Significance of 3D Digital Technology in Urban Sculpture

2.4.1 Limitations of Digital Sculpture

Nevertheless, there are still some limitations to this type of sculptural creation that remain present today. As one can see, this kind of modern invention in sculpture arose as an outcome of computer science and internet technology developments [31, 32]. Even though digital technologies make the work of sculptors easier and contribute to more vivid presentations, they also have some distinctive features.

(1) Deficiencies in Spatial Expression

Digital sculpture shows some limitations in the presentation of space.

The conventional sculptor has some interactions with the work that he/she creates in terms of space, and he/she mainly depends on his/her perceptions of the object and the space. He/she uses experience to gauge the suitability of the space and incorporates it in the creation process. When making digital sculptures, there are some limitations imposed by the virtual world, which make the creator misjudge the space.

(2) Technical Dependency

The technique of digital sculpture is highly dependent on technology, involving the use of software and hardware, which necessitates that the artist have specific computer skills. With frequent advances in technology, the process can be complicated for preservation and cause data loss. While refining the digital sculptures, there are many unpredictable factors that interrupt the sculptor's creativity process. An example of such a factor is a crash caused by too much algorithm or elements, causing a loss of the work done or even the original sculpture itself.

(3) Copyright and Reproducibility Issues

Digital sculptures generally occur in electronic files, thus making duplication quite easy and convenient. This situation brings into focus questions about copyright and reproduction. For instance, ease of reproduction might encourage copyright violation and theft, hence destroying the credibility of the format as an art form. Conversely, too much duplication could rob the piece of its authenticity and artistic merit.

Having taken into account the constraints that affect digital sculpture, there is no doubt that the future progress in urban sculpture must be based on the combination of digital and craft.

2.4.2 The Organic Integration of Digital Technology and Traditional Craftsmanship

Digital technology in three dimensions has a vital role to play during the initial concept design and prototype design phases of urban sculptures. It makes the process convenient during the early phases of design.

A conventional method of creating contemporary urban sculptures is represented in Figure 1 below.

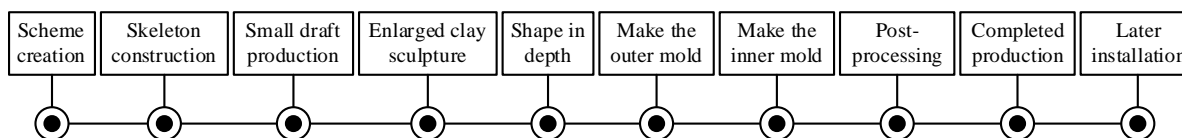


Figure 1: Contemporary urban sculpture traditional creation process

The use of 3D digital technology in urban sculpture design is shown in Figure 2.

One can clearly observe that there are two possible ways to create an urban sculpture with the help of 3D digital technology. One method will involve the combination of conventional

techniques used by artists for sculpting and the application of 3D technology during the creation of the sculpture. The other technique will see the use of computer-aided 3D technology in designing the sculpture, while the modeling information will be sent to a 3D printer firm or to a CNC machine for its construction.

3D digital technology helps in constructing the unpredictable and complicated structure of the urban sculptures, thus outperforming conventional sculpting techniques. Consequently, one can state that the use of 3D technology in creating urban sculptures opens up new possibilities in sculpture design.

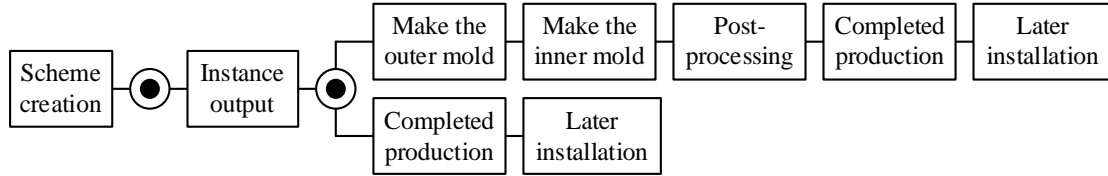


Figure 2: 3D digital technology intervention in urban sculpture creation process

3 Traditional Sculpture Reproduction Based on 3D Reconstruction Technology

3.1 Point Cloud Acquisition Scanning Algorithms and Preprocessing Algorithms

Principle of the Robot Scanning Path Algorithm: Measure the sculpture dimensions and set the initial scanning step size. The program determines whether the model width is less than the length of a single laser beam. If less, the robot and line laser only need to scan once along the model's length. If greater, the algorithm automatically recalculates the scanning step size and determines the number of scans required along the model's length. The calculation formula for the number of scans is:

$$t = \left\lceil \frac{x + D}{s} \right\rceil \quad (1)$$

In the formula, t represents the number of scans along the length direction. s denotes the initial step size, x is the width of the relief model, and D is the margin beyond the edge in the width direction of the model. Therefore, it must be added during calculation. The formula for the new step size is:

$$s_n = \frac{x + D}{t} \quad (2)$$

Based on the scan count and new step size, the coordinate points of the robot's scanning path can ultimately be obtained. These coordinate points are input into the path calculation program, where the algorithm generates the robot's motion path program. For example, if the sculpture model measures 500mm in length and 450mm in width, the scanning path algorithm calculates the number of scans t as 6 and the new step size s_n as 75mm, thereby determining the path's coordinate points.

Acceleration/deceleration and return path errors during the robot's reciprocating motion affect measurement accuracy. To address this, the line laser is offset a certain distance in both

directions along the y-axis during scanning. During final data processing, this offset portion is discarded as invalid data.

Based on the new step size s_n obtained from the scanning path algorithm and the object's length y , a coarse displacement stitching of the point cloud is performed. This essentially involves translating the target point cloud by a certain distance, expressed as:

$$P' = P + d \quad (3)$$

In the equation, P' represents the translated point cloud data. P denotes the target point cloud requiring displacement. d is the displacement distance vector. Their coordinate forms are:

$$P' = \begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix}, P = \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}, d = \begin{pmatrix} \partial_x \\ \partial_y \\ \partial_z \\ 1 \end{pmatrix} \quad (4)$$

Thus, we obtain:

$$x' = x + \partial_x, y' = y + \partial_y, z' = z + \partial_z \quad (5)$$

The transformation process from P to P' can be expressed as $P' = TP$, where the transformation matrix T is generally referred to as the translation vector, defined as:

$$T = T(\partial_x, \partial_y, \partial_z) = \begin{pmatrix} 1 & 0 & 0 & \partial_x \\ 0 & 1 & 0 & \partial_y \\ 0 & 0 & 1 & \partial_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (6)$$

3.2 Automatic Cloud-Based 3D Reconstruction Optimization for Sculpture Points

3.2.1 Feature Extraction from Sculpture Point Sparse Images

By employing three-dimensional corner detection and edge contour feature extraction methods, we optimized the automatic three-dimensional reconstruction method for sculpted point sparse images based on feature detection of three-dimensional point clouds.

Feature decomposition is performed using gradient operations to reconfigure the edge contour information of sparse point images. Based on the principle of transversality, a sparse linear equation system is constructed to achieve continuous segmentation of sparse point images. The 3D shape template matching value is:

$$\frac{\langle \tau_d u', \tilde{u} \rangle_{\varphi_+}}{\|\tau_d u\|_{\varphi_+} \|\tilde{u}\|_{\varphi_+}} - \frac{\langle \tau_d u, \tilde{u} \rangle_{\varphi_+} \langle \tau_d u', \tau_d u \rangle_{\varphi_+}}{\|\tau_d u\|_{\varphi_+}^3 \|\tilde{u}\|_{\varphi_+}} \quad (7)$$

The sparsity decomposition process for the sparse image of the sculpted points is as follows:

$$\begin{aligned}
& \frac{\partial}{\partial d} \left(\frac{\langle \tau_d \mathbf{u}, \bar{\mathbf{u}} \rangle_{\varphi_s}}{\|\tau_d \mathbf{u}\|_{\varphi_s} \|\bar{\mathbf{u}}\|_{\varphi_s}} \right) \\
&= \frac{(\|\tau_d \mathbf{u}\|_{\varphi_s} \frac{\partial}{\partial d} (\langle \tau_d \mathbf{u}, \bar{\mathbf{u}} \rangle_{\varphi_s}) - \langle \tau_d \mathbf{u}, \bar{\mathbf{u}} \rangle_{\varphi_s} \frac{\partial}{\partial d} (\|\tau_d \mathbf{u}\|_{\varphi_s}))}{(\|\tau_d \mathbf{u}\|_{\varphi_s})^2 \|\bar{\mathbf{u}}\|_{\varphi_s}} \\
&= \frac{\langle \tau_d \mathbf{u}', \bar{\mathbf{u}} \rangle_{\varphi_s}}{\|\tau_d \mathbf{u}\|_{\varphi_s} \|\tilde{\mathbf{u}}\|_{\varphi_s}} - \frac{\langle \tau_d \mathbf{u}, \bar{\mathbf{u}} \rangle_{\varphi_s} \langle \tau_d \mathbf{u}', \tau_d \mathbf{u} \rangle}{(\|\tau_d \mathbf{u}\|_{\varphi_s})^3 \|\tilde{\mathbf{u}}\|_{\varphi_s}}
\end{aligned} \tag{8}$$

In the equation, $\|\tau_d \mathbf{u}\|_{\varphi}$ denotes the merged weakly convex component feature quantity. $\langle \tau_d \mathbf{u}', \tilde{\mathbf{u}} \rangle_{\varphi_i}$ represents the residual quantity of the signal decomposition on the optimal atom. $\langle \tau_d \mathbf{u}, \tilde{\mathbf{u}} \rangle_{\varphi_i}$ denotes the component of the signal decomposition on the optimal atom. $\langle \tau_d \mathbf{u}', \tau_d \mathbf{u} \rangle_{\varphi_i}$ denotes the residual component after optimal matching. $\|\tilde{\mathbf{u}}\|_{\varphi}$ represents the atom used for coefficient decomposition.

Employing a gradient operation method for feature decomposition, we perform information fusion processing on the sparse point cloud data of the detected sculpted points. This yields the edge information feature components of the sparse sculpted point image:

$$is_visible(M_d(C_i), TC) = \begin{cases} 1, & \text{if } \begin{cases} j \neq i, \\ C_j \text{ may call } M_{mi} \end{cases} \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

In the equation, TC denotes the smoothing operator for reconstructing sparse images of sculpted points. $M_d(C_i)$ represents key feature points in the point cloud C_i . The continuous reconstructed feature component at point (a, b_m) on the reconstructed sparse image surface of sculpted points is:

$$L(a, b_m) = \log(M_d(C_i) \frac{|V \cap V_m \cap V_n|}{|V_m \cap V_n|}) \tag{10}$$

In the above equation, $|V|$ denotes the sparse image set, $|V_m|$ denotes the sparse image set in the neighborhood, $|V_n|$ denotes the sparse image set corresponding to the sampling point, and $|V_m \cap V_n|$ denotes the sparse image set corresponding to the sampling point in the domain. In point cloud reconstruction, a moving least squares method is used to fit the local surface at the point. Image 3D reconstruction is performed based on sparse scattered point 3D reconstruction and template feature matching for sharpening.

3.2.2 Automatic Cloud-Based 3D Reconstruction Output for Sculpture Points

The Sigma model is employed for continuous 3D point cloud reconstruction of sparse point clouds from sculpted objects. Within a neighborhood of radius r , the sparse point cloud undergoes block segmentation and template feature matching, specifically:

$$L(a, b_m) = \sum_{V_n \in P^n, V_m \in P^n} \frac{|V_m \cap V_n|}{|V|} \log \left(\frac{|V| \|V_m \cap V_n|}{|V_m| \|V_n|} \right) \quad (11)$$

In the above equation, p^{res} represents a hypothetical measure of image distortion, while p^{true} denotes an actual measure of image distortion. On the matching points of the mesh model, perform information enhancement processing on the sparse image of the sculpting points. This yields the mesh model matching points for the sparse image of the sculpting points:

$$\bar{x}_T = \frac{1}{T} \sum_{i=1}^T x_i \quad (12)$$

Among these, $x_1, x_2, x_3 \dots x_T$ represent the characteristic sub-samples of the template shape. T denotes the characteristic components of the 3D reconstruction from the automatic point cloud of the sculpted points. Establish a statistical shape model for the sparse image of sculpted points. Apply Taubin smoothing to the entire mesh model to obtain two sets of adjacent pixels:

$$F = \tilde{p}(x, y) = p(x, y) \left(\frac{v(x)}{v(y)} \right)^{1/2} \quad (13)$$

In the above equation, $\tilde{p}(x, y)$ denotes the grayscale value of the sparse component reconstructed image. $p(x, y)$ represents the approximate grayscale value of the denoised pixel. $v(x)$ indicates the horizontal deformation vector, while $v(y)$ denotes the vertical deformation vector. Where:

$$p(x, y) = \frac{k(x, y)}{v(x)}, v(x) = \sum_y k(x, y) \quad (14)$$

Using a neighborhood search method for rapid feature point localization and information enhancement processing of sparse point clouds from sculpted images, the diameter of the computational mesh model is obtained as follows:

$$E_{int}(v_i) = \frac{1}{2} F(\partial i | \mu - |v_i - v_{i-1}| |^2 + \beta i |v_{i-1} + 2v_i + v_{i+1}|^2) \quad (15)$$

In the above equation, μ denotes the scale reference value. v_i represents the deformation vector of the i th curve. ∂i denotes the derivative of the grayscale value in the sparse image of the sculpted point. βi denotes the control point relative to the i th curve. Where:

$$\mu = \frac{1}{n} \sum_{i=0}^{n-1} |v_i - v_{i-1}| \quad (16)$$

Based on the above processing, perform automatic point cloud feature decomposition for each layer l along the longitudinal direction. Let P_n and P_{n+1} denote the sampled point clouds after the n th and $(n+1)$ th data collection points, respectively. The output gradient

vector $T(g_i)$ for point cloud reconstruction is expressed as follows:

$$G_{new} = (1 + \mu T)(1 + \lambda T)G_{old} \quad (17)$$

$$T(g_i) = \frac{1}{\sum_k T_n} \cdot \sum_k T_n (P_{n+1} - P_n) \quad (18)$$

In this context, G_{new} and G_{old} respectively represent the sampled point cloud matching coefficients and deformation parameters. $T_n = (f, g, h)_n$ denotes the deformation parameters from P_n to P_{n+1} . Based on the above analysis, the expression for the automatic 3D reconstruction of the sculpture point cloud is obtained as:

$$d_i^{k+1} = (1 - \mu)d_i^k + \frac{\left(\sum_{j < N(i)} (E \text{int}(vi)) \frac{g_i + g_j}{2} + (1 - \mu)d_j^{k+1} + \sum_{j < N^{-1}(i)} (E \text{int}(vi)) \frac{g_i + g_j}{2} + (1 - \mu)d_j^k - \frac{T(g_i)}{G_{new}} \right)}{\sum_{j < N(i)} (E \text{int}(vi)) \frac{g_i + g_j}{2} + (1 - \mu)} \quad (19)$$

The above equation represents the grayscale pixel characteristics of the sparse image of the sculpted point. Based on the comprehensive analysis, the algorithm was improved and redesigned. The reconstructed image preserves and enhances the low-frequency components, thereby improving the reconstruction quality.

3.3 Simulation Tests and Results Analysis

The point cloud acquisition device for this experiment employs a 3D scanner to collect object point cloud data. Concurrently, the collected point clouds are analyzed through the host computer terminal having specifications such as 8 GB of RAM, 1 TB of storage space, and a CPU of Intel® i7-4200H type.

In order to assure that the program code compiles properly and functions smoothly with all types of operating systems, the software tool will be created under the Windows operating system. Visual Studio 2023 will be used with the help of PCL development environment. The implementation of algorithms will take place in C++.

3.3.1 Application Examples of 3D Point Cloud Reconstruction

The parameters used for conducting this experiment are in the form of curvature within the range of [0.01, 0.10] and normal vectors angle of [30°, 180°]. Feature-constrained simplification experiments and three-dimensional reconstruction experiments were performed on five experimental objects.

Figure 3 shows the statistical data on the number of local features point clouds per model. In this case, there is data on the number of point clouds in five experimental objects with curvature values of [0.01, 0.10] based on the method of automatic point cloud three-dimensional reconstruction through the sparse image sequence. At a curvature value of 0.02, Einstein Bust sculpture gave only 10,112 points of data in feature point clouds, which probably belongs to the bottom of the sculpture.

Analysis of the final results from the experiment reveals that the suggested approach is

effective in extracting feature constrained point cloud data for five models; coffee cup, potted plant, gear model, Einstein sculpture, and Chibi Maruko-chan.

In regard to critical features like the curvatures for the potted plant’s transition surfaces, the mouth and hair portions of the bust statue, the texture of the Chibi Maruko-chan character figure, the teeth and shaft sleeves of the gear, and the shape of the coffee cup itself, this process has been successful in extracting the point clouds from those regions.

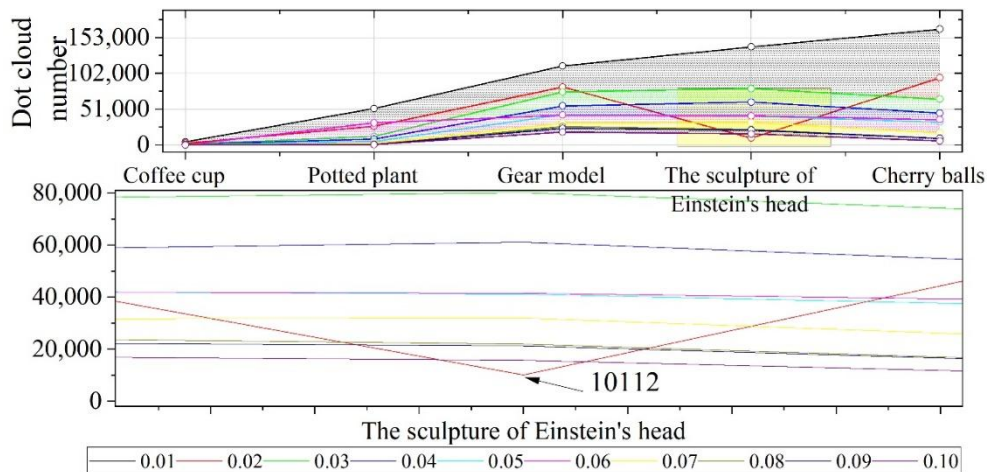


Figure 3: The local feature point cloud quantity statistics of the model

The overall point cloud count statistics for the models are shown in Figure 4.

As the point cloud curvature threshold increases, the final point cloud counts for all experimental object models decrease accordingly. However, due to the greater complexity of the gear model's point cloud, the final point cloud data volume for the gear model exceeds that of the other models. This validates the effectiveness of the proposed method for point cloud models with varying quantities and complexities, while also confirming its applicability.

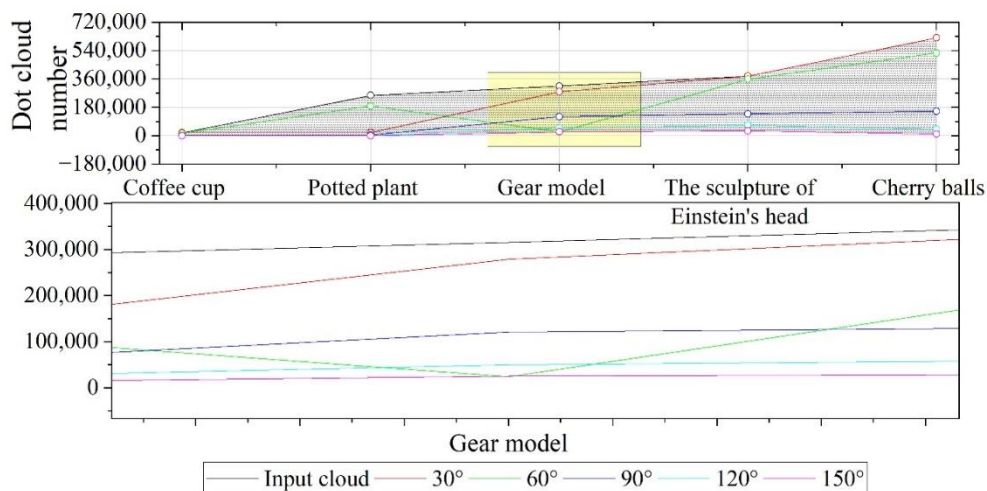


Figure 4: The overall feature point cloud quantity statistics of the model

For five distinct types of data models, the proposed method of automatic 3D reconstruction using sparse image sequences and sculpted point clouds was applied. The resulting number of faces in the reconstructed models is shown in Figure 5.

Analyzing the proportion of total face counts across the five object datasets, the proposed method achieved processing times of 4.12s, 12.11s, 15.68s, 23.54s, and 34.87s for the coffee

cup, potted plant, gear model, Einstein bust sculpture, and Cherry Momo figurine, respectively.

The combined experimental results fully validate that the proposed sparse image sequence-based automatic point cloud 3D reconstruction method for sculptures can reconstruct target models with fewer triangular faces while preserving structural features, confirming the effectiveness of this reconstruction approach.

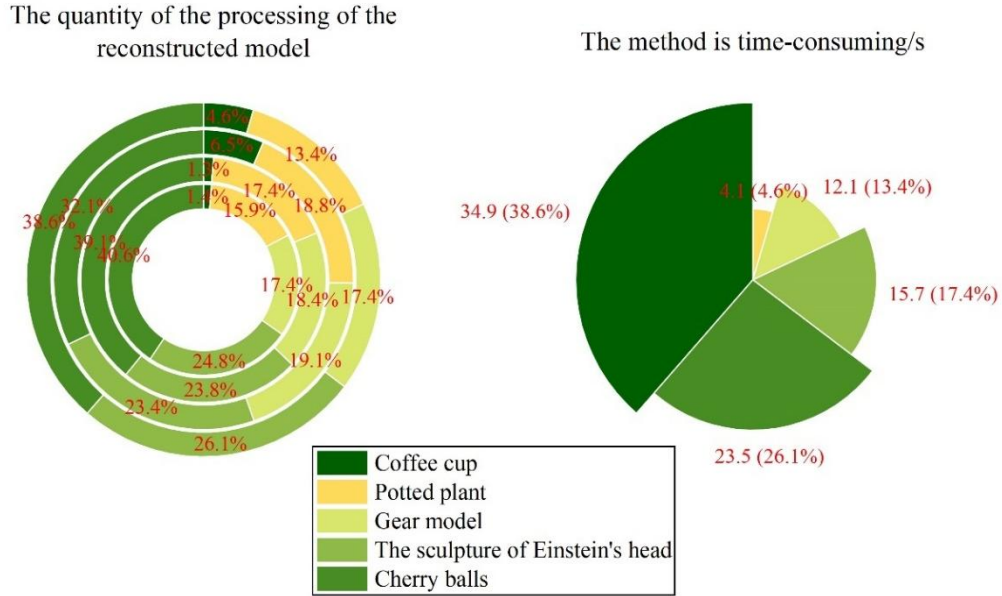


Figure 5: The quantity of the processing of the reconstructed model

3.3.2 Algorithm Timing Statistics

The algorithm runtime statistics shown in Figure 6 illustrate the reconstruction time for dihedral angles and cylinders across various algorithms at different iteration counts. For the proposed method, reconstruction times for dihedral angles at 8, 16, and 24 iterations were 0.825s, 2.278s, and 3.669s, respectively. For cylinders, the corresponding times were 1.778s, 3.451s, and 5.263s.

As APSS and RIMLS are local optimization methods, they exhibit superior temporal efficiency compared to the globally optimized L0 method and the proposed method. The proposed method's computational time is slightly higher than that of the L0 method, which achieves the highest reconstruction accuracy among the three typical methods.

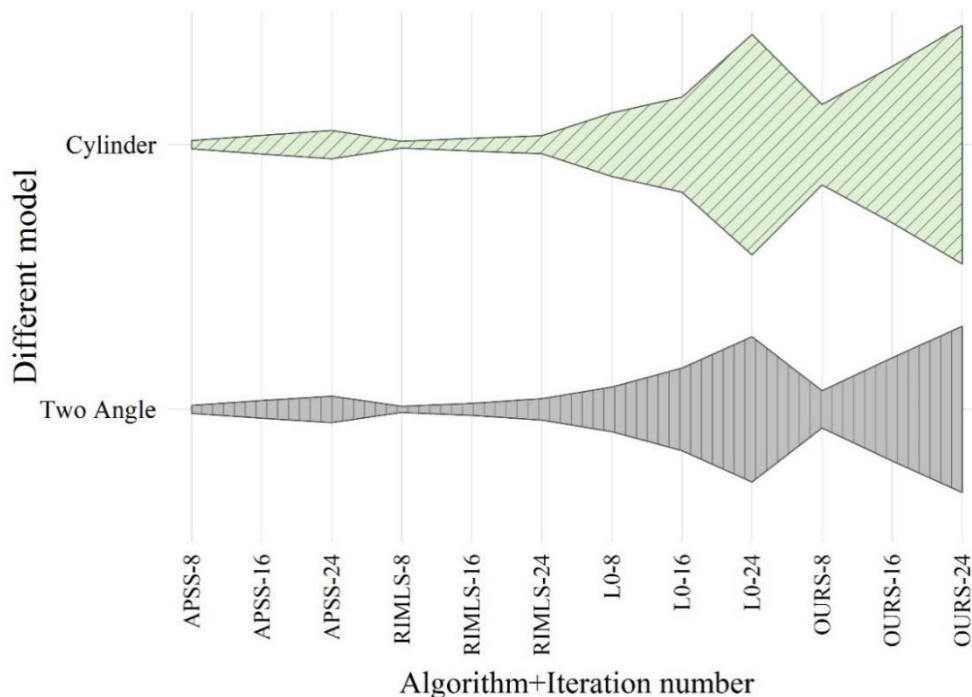


Figure 6: Algorithm time-consuming statistics

3.3.3 Sculpture Reconstruction Effects

In modern surveying, LiDAR serves as an important non-contact measuring tool. It mainly functions by sending out laser beams that produce signals upon interacting with the environment and reaching the targeted object while moving through space. Through measuring the time taken for these beams to travel from their point of emission to the targeted object, it becomes possible for LiDAR to accurately measure the precise distance from the object to the radar. LiDAR also manages to scan its surroundings by constantly altering the angles of emitted laser beams.

Three-dimensional point cloud data refers to a set of three-dimensional coordinate points that follow certain laws. By adopting advanced active optical remote sensing technology, it quickly conducts three-dimensional scanning of the object whose shape is difficult to determine. In the process of scanning, the three-dimensional coordinates of the reflected points captured on the surface of the object are recorded. With the scanning of the lidar, the distance and angle of the reflected points are carefully recorded. After subsequent complex data processing, a point cloud data set composed of many three-dimensional coordinate points can be obtained. Such a three-dimensional point cloud data set can provide an accurate representation of the three-dimensional environment, providing solid data support for subsequent analysis. Three-dimensional point cloud data plays an irreplaceable role in any field, which helps us analyze the three-dimensional environment more accurately.

The three-dimensional point cloud distribution of the Urban Volcano sculpture is shown in Figure 7.

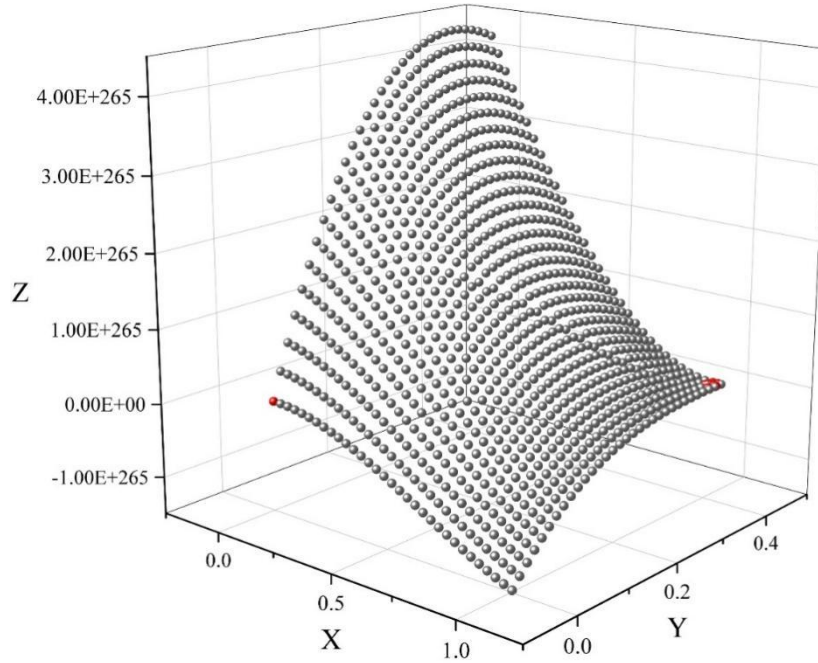


Figure 7: Urban volcanic sculpture point cloud data

To reconstruct the three-dimensional structure of the urban volcanic sculpture, the height information of the 3D point cloud was removed, converting it into a two-dimensional planar point cloud. The distribution of the urban volcanic sculpture's 2D point cloud is shown in Figure 8.

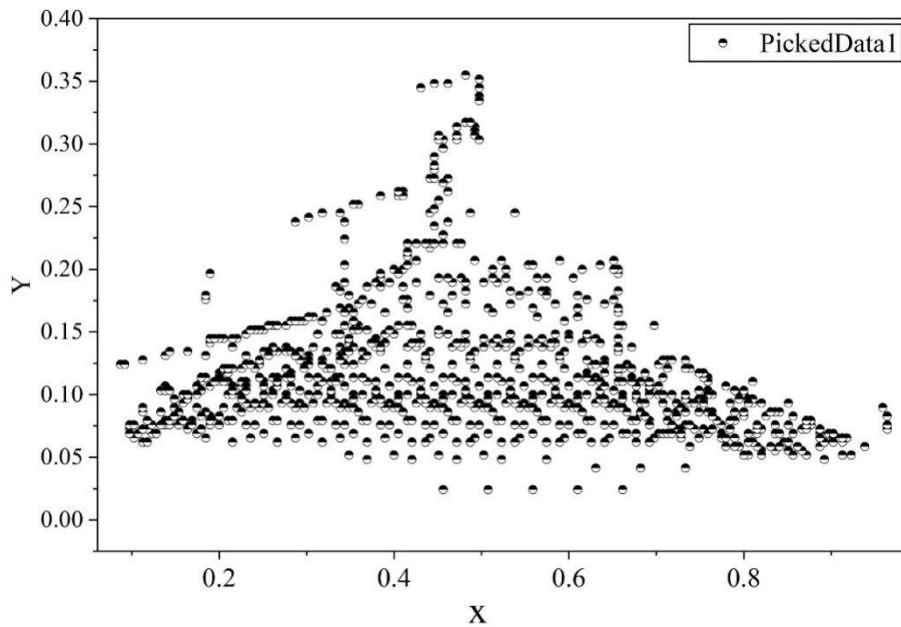


Figure 8: The two-dimensional point cloud distribution of urban volcanic sculpture

The 3D reconstruction of the simulated city volcano sculpture is shown in Figure 9.

This paper employs the proposed sparse image sequence-based automatic point cloud 3D reconstruction method for sculptures. The generated mesh effectively conforms to the surface morphology of the volcano sculpture while significantly reducing the number of mesh elements. Key areas have been appropriately refined, ensuring high-quality 3D reconstruction of the

volcano sculpture while simplifying the mesh count and substantially improving reconstruction speed.

Integrating the proposed 3D digital technology into the urban sculpture creation process (Figure 2) and combining it with traditional sculpting techniques allows for the appropriate incorporation of 3D methods into the urban sculpture production stages, ultimately completing the creation of the urban volcanic sculpture. Nevertheless, the seamless fusion between the 3D digital technology and the conventional techniques used in sculpting does present some limitations. The sculptor should not overly rely on technology in an attempt to “demonstrate technical skills” for fear of descending into “beauty without substance.” Hence, while making modern urban sculptures such as the volcano, the sculptor is obliged to do extensive optimization and fine-tuning. Through the use of conventional techniques, the cultural spirit of the sculpture will be effectively captured.

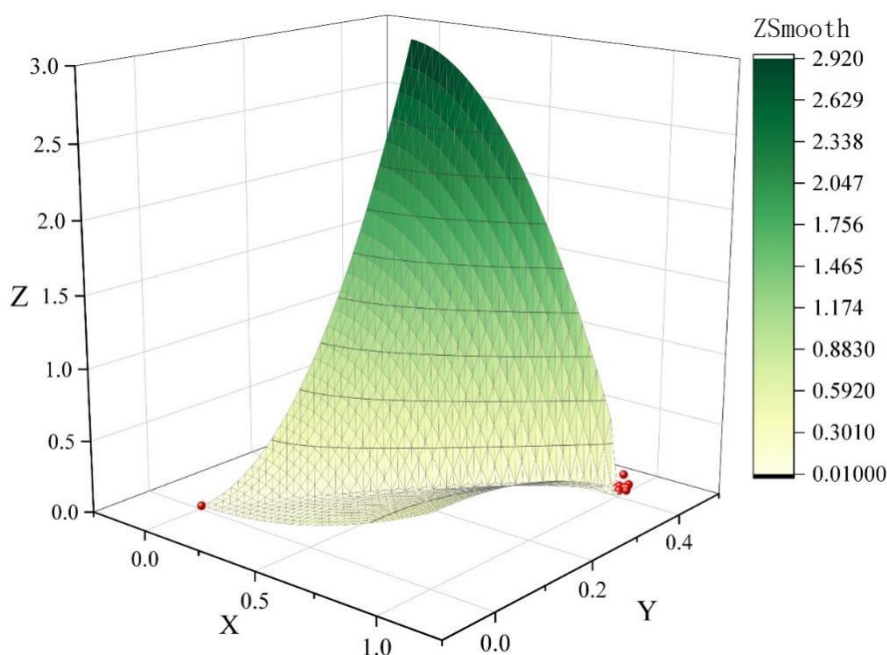


Figure 9: Three-dimensional reconstruction of urban volcanic sculpture

4 Conclusion

The importance of 3D digital technology in urban sculpture is analyzed in this paper. The solution to integrate the use of 3D digital technology in urban sculpture design is presented. Based on 3D modeling techniques, the automatic reconstruction of point cloud 3D technology used in sculpture creation is improved.

The sparse image sequence-based automatic point cloud 3D reconstruction method successfully extracts details from experimental subjects including potted plants, coffee cups, and the Einstein bust sculpture. Key features validated include the curved transition surfaces of the potted plant, the mouth and hair sections of the bust sculpture, surface textures of the Cherry Momoko figurine, tooth profiles and shaft sleeves of the gear model, and the overall contour of the coffee cup. This demonstrates the effectiveness of the feature-constrained approach. The method achieves effective 3D reconstruction of dihedrals and cylinders within 6 seconds.

The 3D reconstruction results demonstrate that combining the automatic point cloud 3D reconstruction method enables the reproduction of representative urban volcanic sculptures. This can be regarded as an effective development integrating traditional artistic features with

modern digital technology.

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