AN ANALYSIS METHOD OF THE AMOUNT OF BRICKS USED IN PUZHOU ANCIENT CITY WALL BASED ON SLAM

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KEY WORDS: SLAM, PuZhou Ancient City, Drum Tower, Amount of bricks used, City wall

ABSTRACT:

The calculation of the amount of bricks used in the area of falling-off is of great significance to the restoration of the ruins of ancient cities In order to support the digital restoration of the city wall of Puzhou Ancient City Site, this paper analyzed and calculated the amount of outer cladding brick of the city wall based on SLAM data. Firstly, the point cloud data of Puzhou city wall is obtained by SLAM technology. Secondly, the original point cloud is processed by Geomagic Studio software, and the area of the damaged area is accurately measured from the packaging model. Finally, based on the characteristics of brick masonry of ancient city walls, this paper estimates the amount of brick used in the area where the external wall of drum tower falls off, thus providing data support for the repair and maintenance of Puzhou ancient city.

1. INTRODUCTION

Puzhou ancient city site is an important cultural heritage site in China., which embodies the wisdom of the ancient working people and carries the history and culture, and has important research value. Due to the influence of natural and man-made factors such as rainwater erosion erosion, erosion and tourism development, the ancient city wall of Puzhou city appears different degree of disease and damage, in which the falling off of the bricklaying surface layer directly threatens the safety of the wall structure. Therefore, Puzhou ancient city wall’s protection and the repair is imminent.

Digital restoration technology is an important means of cultural heritage protection, which can not only restore the damaged sites to a specific historical state, but also avoid secondary damage caused by improper restoration of the site entities. According to the principle, it can be divided into three types: total station mapping technology based on single point survey, photogrammetry technology and three-dimensional laser scanning technology. The traditional single-point surveying technology mainly uses theodolite, total station, GPS-RTK and other surveying instruments to acquire the coordinates of discrete points on the surface of the ruins, and realizes digital mapping and restoration through indoor point mapping. Because single-point measurement cannot obtain the three-dimensional coordinates of a large number of space points quickly, it is inefficient and costly for large-scale and complicated ancient sites. The 3D reconstruction technology based on photogrammetry theory mainly depends on the intersection of light in the image to calculate the spatial point, which requires high light and visibility. Based on the principle of laser ranging, 3D laser scanning technology can quickly obtain massive point clouds and has the advantages of high data accuracy. Ground three-dimensional laser scanning (TLS) has been widely used in the virtual restoration of cultural heritage, but this technology involves the registration and splicing of scanned data. Therefore, in the practical application scene, it is necessary to ensure that there are homonymous elements between the adjacent stations. In addition, the registration error is easy to be introduced into the indoor processing, which affects the data accuracy and operation efficiency. Over the past decade, ground-based three-dimensional laser scanning (TLS) to obtain fine geometry, combined with UAV tilt photography to quickly obtain a wide range of external points is the main means to collect complex heritage objects (Alshawabkeh et al.2020). It is widely used in the virtual restoration project of cultural heritage. Digital Reservation is the primary work of cultural heritage protection project. Digital technology based on multi-sensor capturing reality provides a powerful tool for high-precision data collection of cultural heritage sites.Murtiyoso（Murtiyosoet al.2018；Malaet al.2019;

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Nofalet al.2018), the multi-sensor fusion technology using UAV, camera and TLS has been applied to the digital engineering of heritage sites to extract orthophoto images (Chiabrando et al.2015), the vector model of the facade (Cefaluet al.2013) , 3D model, Heritage Building Information Model (Quattrini et al.2015 3D models, heritage building information models (Quattrini et al.2015). On the other hand, the high-precision digital model can provide data support for the virtual restoration of the legacy object, thus guiding the decision of the entity restoration. Chen (Chen et al.2016) based on the mechanical analysis of the key size information from the digital model, the shape of the ancient stack road and the size of the defective parts were deduced, and the virtual repair of the damaged stack road was carried out by means of human-computer interaction. Wang (Wang et al.2020) and others use social media images uploaded by tourists to reconstruct the Moon Gate of the Ming Great Wall in Shanxi Province, which is an existing collapsed great wall enemy building. However, 3D reconstruction based on images is harsh to the photography environment and conditions, and TLS technology involves registration and splicing of scanning data. In practical application scenarios, it is necessary to ensure that there are elements of the same name between adjacent stations. In the technical process based on multi-source data fusion, internal processing is easy to introduce registration errors, which will affect the data accuracy. Wang (Wang et al.2020) and others use social media images uploaded by tourists to reconstruct the Moon Gate of the Ming Great Wall in Shanxi Province, an existing collapsed enemy tower of the Great Wall. Based on the size information of the reconstruction, the virtual restoration is realized in 3D MAX software. However, the image-based 3D reconstruction is harsh to the photographic environment and conditions, and the TLS-based technology involves the registration and stitching of the scanned data. In the practical application scene, it is necessary to ensure the existence of the same name elements between the adjacent stations. In the technical process based on multi-source data fusion, internal processing is easy to introduce registration errors and affect data accuracy.
Considering the above problems, this paper presents an analysis method of brick requirement for wall repair by SLAM technique. The base point cloud data of the drum tower city wall in Puzhou is obtained by SLAM, and the amount of bricks needed for the wall repair is analyzed by the area of bricks falling off and the construction technology. This method avoids the complicated point cloud fusion flow, improves the work efficiency and the data quality, overcomes the subjectivity of the manual estimation of the quantity of bricks used, and provides the accurate data basis for the protection and repair of Puzhou ancient city.

2. STUDY AREA AND MATERIALS

2.1 Research area

As shown in Figure 1, the ruins of Puzhou Ancient City is located on the east bank of the Yellow River, about 17 kilometers southwest of Yongji City, Yuncheng City, Shanxi Province, with 110°14' east longitude and 34°84' north latitude. Founded in the Northern Wei Dynasty, after repeated reconstruction and expansion, it is an important historical town in northern China. The research area of this paper is the bottom platform of the Drum Tower System in the center of Puzhou Ancient City Ruins.

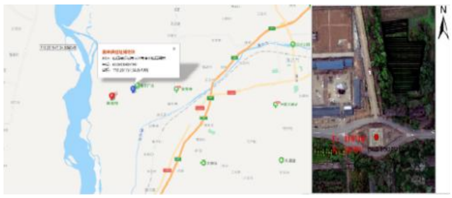


Figure 1. Map of Drum Tower, Puzhou ancient city

The platform at the bottom of the Drum Tower is square in plane, as shown in Figure 2. The platform is 9.4 meters high and there are doorways on all sides that connect with each other in the cross. The original four doorways all have inscribed boards and couplets. Four door brick bond masonry basically intact, the bottom of 1 meters high ghee; Only about 1 meter high is left at the bottom of the four-faced brick masonry, while the rest have been dismantled and lined with exposed small brick masonry. The existing bottom platform of the Drum Tower is mainly missing most of the outer clad city bricks. The purpose of this study is to digitize the existing wall of the bottom platform of the Drum Tower and estimate the amount of bricks used for the detached part of the outer cladding brick.

Figure 2. Ruins of Drum Tower System in Puzhou Ancient City

2.2 Brick size of Drum Tower City, Puzhou

According to historical data and archaeological records, the sizes of bricks vary in different historical stages. According to the size data of city bricks compiled by Mr.Jia Tingli, it can be concluded that the specification of city bricks began to be customized in the Ming dynasty, and the size of city bricks before the Ming dynasty is reflected in the overall thin thickness of city bricks. According to historical records such as "Ming Shi Lu" and "Yongle Da Dian", cities were built on a large scale in the Ming Dynasty, especially during the Hongwu reign. Compared with the previous dynasties, the size of the bricks increased significantly, and the shape and structure of city bricks began to be basically determined, in which the length, width and thickness of city bricks basically formed a law of decreasing by half. The city brick samples were successively selected from the east, south, west and north wall of the Ming Dynasty Drum Tower of Puzhou, and the measured data were summarized in Table 1
According to the above data, it can be concluded that the Ming Dynasty wall bricks of Puzhou old city generally conform to the size of length, width and

thickness, which basically forms the law of decreasing by half. From this we can roughly infer that the city construction system in Ming Dynasty has formed a certain standard. The average size of wall brick is 24*11.5*0.5(cm).

Bick position	Data（cm）			Mean value（cm）		
	length	wide	thickness	length	wide	thickness
North Wall	26	12.5	5	24	11.5	5
East wall	24	13	4			
South wall	24.5	10	5			
Western Wall	23.5	10.5	5			

Table 1 Summary of Drum Tower City Brick Sampling Data

3. METHODOLOGY

Figure. 3 is the technical route of the brick volume analysis method proposed in this paper, which mainly includes: field survey, SLAM data acquisition, point cloud data processing, falling area measurement and Amount of brick analysis for the repair of Drum Tower city wall.

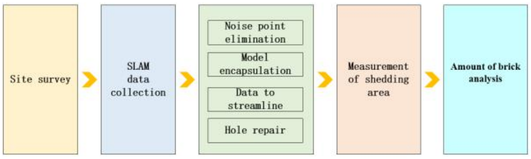


Figure 3. the technical road map for the main content

3.1 data acquisition

The study area is located in the center of Puzhou ancient city site of the Drum Tower. The instrument used in this data collection is the Geo SLAM handheld 3D laser scanner of CETC (as shown in Figure 4). The main parameters of the scanner are shown in Table 2. Compared with the traditional mobile or fixed station scanner, the instrument is simple to operate and belongs to mobile laser scanning. It does not need GPS and inertial navigation system, station changing and splicing. It can collect and acquire complete and coherent point cloud data of the object, and has the advantages of fast data acquisition, high accuracy and convenient data processing. In this paper, based on SLAM 3D laser scanning technology, integrated point cloud data acquisition and 3D modeling is carried out for the Drum Tower Base Site.

Figure 4. SLAM 3D Laser Scanning

Maximum ranging	30m
Data acquisition rate	43200 point/second
Resolution	Level:0.625°/ vertical:1.8°
Field angle	270°*360°
Relative accuracy	1-3m
Absolute accuracy	3-30cm（：10 minute scan, closed loop）
Software	GeoSLAM Desktop V3 or GeoSLAM Hub
Speed of rotation	0.5Hz
Scanner resolution	Level:0.625°
Linear sweep rate	100Hz
Default output file format	LAS/PLY/E57
Laser Line	905nm
Laser safety grade	First level safety for human eyes

Table 2 Main Specifications of Geo SLAM

In view of the characteristics of the bottom platform of Puzhou Drum Tower, in order to obtain complete data and reduce data missing, the scanning route is set as a closed route: top - inside - door opening - outside - top. The collected point cloud data is shown in Figure 5.

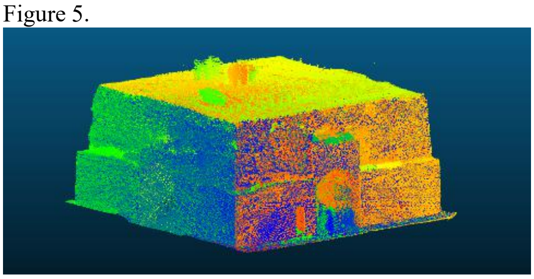


Figure 5. Raw point cloud data

3.2 data processing

In this paper, a commercial software Geomagic Studio is used to process the SLAM point cloud, which mainly includes noise point elimination, model encapsulation, data simplification and hole repair. Since the scanning data contains noise points, which are distributed on the surface of the city wall, the noise should be eliminated before forming the triangle net to avoid affecting the quality of the network. In the model packaging step, the maximum number of triangular faces should be set as X to realize the conversion from point object to polygon object.The processing of models with a large number of triangular plates requires more resources and higher performance requirements on the equipment, leading to long computation time in the following steps, thus affecting the operation efficiency. To avoid this problem, you can use the "simplify" tool to reduce the number of triangulations without affecting the detail and color of the surface. Triangulation optimization is important for model quality and estimation accuracy, so the "mesh doctor" feature provides a variety of optimization tools, such as the ability to analyze non-popular edges, highly refractive edges, remove pegs, fill small holes, etc. At last, manual hole filling is carried out in the software. In this stage, appropriate mode is selected for different missing holes to repair the internal holes, boundary holes and areas that need to be bridged. The result was a complete model of the wall of the Drum Tower, Figure 6 shows the comparison between the model and the real ancient city wall. to get a complete model of the Drum Tower wall.

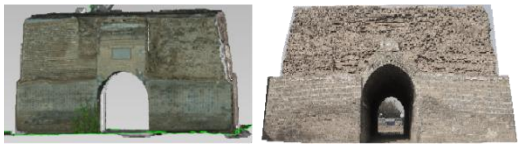
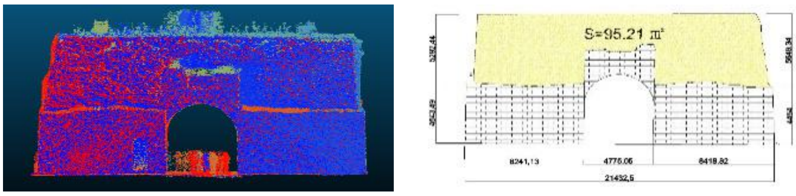


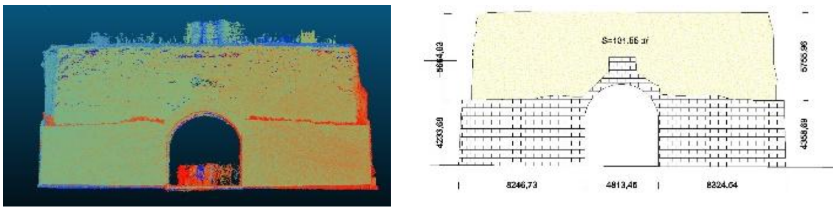
Figure 6. The model is compared with the real ancient city wall

3.3 Measuring the area of the shedding area

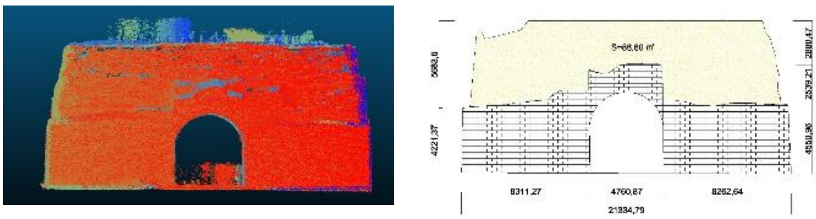
The original point cloud data were imported into CAD to measure the shedding area and basic data of the four walls of the Drum Tower in Puzhou Old City, as shown in Figure 7. According to the measurement, the falling off area of the east wall is 101.55 m^2,The area of wall shedding on the west side is 95.21 m^2, the area of wall shedding on the south side is 80.23 m^2, and the area of wall shedding on the north side is 88.60 m^2. The real data of the measurement provides the analysis of the model measurement results in the later period.



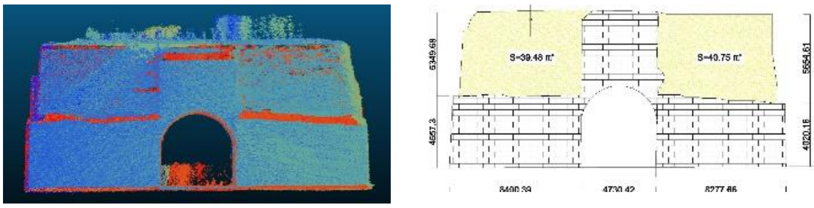
（a）West wall falling off disease



(b) East wall falling off disease



(c) North wall shedding disease



(d)South wall falling off disease

Figure 7. Measurement of falling off area of drum tower

3.4 Amount of brick used analysis

3.4.1 the method of "One line and one ding"

Brick wall was popular in Ming Dynasty, and the brick building method was gradually mature. In order to prevent the cracks of the bricks, the surface layer of most city walls is laid with "Ding" and "Shun" alternating with each other, and the upper and lower brick lines are staggered.

Figure 8. Brick laying of the wall of Puzhou Drum Tower**.**

3.4.2 Stick a method of build by laying bricks or stones:

According to the field investigation, the thickness of the inner and outer wall of the old city in Puzhou is 78 cm, and the thickness of the upper and lower parts is the same or similar. The inner part is inclined to the rammed earth wall, so the brick-cladding form belongs to sticking.

3.4.3 Calculated in bricks:

Take "Nine Chapters of Mathematics" which introduces the engineering amount of the wall quota abbot and the calculation method of its brick consumption as an example. Volume 7 of "Mathematics Nine" Volume 7 "Ying Ting · Planning the City Construction": " The wall is a square meter, multiplied by a hundred feet. The following nine layers, seven in the middle, five on the top, and twenty-one layers, multiplied by two hundred feet, the bricks have inches in length, and the brick length is two hundred and ten thousand inches. If the brick is 12 inches long, multiply the thickness by two inches and five cents, and you will get 30 inches. The method, divide the real, get 7,000 pieces, which are the bricks of the city."

This calculation method is suitable for the wall with single layer brick cladding. For the multi-layer brick cladding of the wall of Puzhou Drum Tower, it is more scientific to calculate the brick amount by volume. Moreover, the volume calculation method can ignore the thickness of the wall brick, the number of layers, and the bricklaying method, and it is more intuitive.

The wall of the old city of Puzhou is roughly laid by sticking bricks, with the same thickness up and down, basically rectangular. The bricks are laid in one straight line and one square. It is not advisable to calculate the amount of bricks used in the city wall according to the calculation method in the Nine Chapters of Mathematics, because there is more than one layer of bricks in the old city. However, the above typical examples are applicable to calculate the amount of bricks used in one layer of the city wall. Therefore, the modern architectural metrology theory is adopted to calculate the amount of bricks used in the old city body:

$$V_{brick} = L \times W \times H$$

$$V_{body} = (H_{wall} - H) \times L_{wall} \times H_{city}$$

$$V_{top} = H \times S_{top}$$

$$V = V_{top} + V_{body}$$

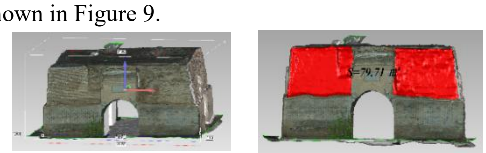
$$N_{brick} = V \div V_{brick}$$

In the formula, V_{brick} represents brick volume, V_{body} represents brick volume, V_{top} represents brick volume at the top of the city wall, V represents the total volume of brick volume at the top of the city wall, L, W and H respectively represent the length, width and thickness of the city brick, H_{wall} represents the height, L_{wall} represents the length, H_{city} represents brick thickness, and S_{top} represents the volume at the top of the wall.

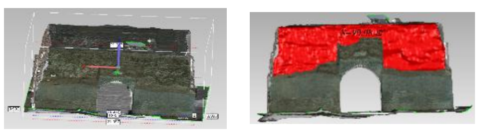
4. EXPERIMENTS AND ANALYSI

In the Geomagic studio13 software, the basic data amount of the built Drum Tower model is measured.

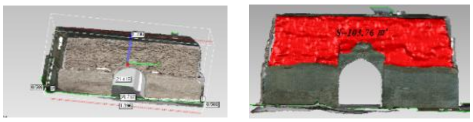
(1) first of all, the length of the platform on the north, south and east sides of drum tower is measured to be 21.302m, 21.416m, 21.397m and 21.001m respectively. According to the records, the platform is square in shape. Therefore, the average value of the platform is calculated to be 21.279m and the perimeter of the city is 85.116m. Take the data as shown in Figure 9.



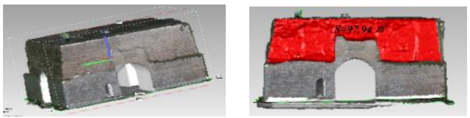
(a) South wall



(b) East wall



（cNorth wall



（d） West wall

Figure 9. Basic data amount of the existing Drum Tower model

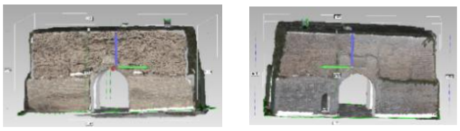


Figure 10. The Drum Tower has a high base

(2) the bottom of the drum tower high measuring 9.603 m, 10.025 m, calculate the average 9.814 m high to the bottom of the drum tower, measuring data is shown in figure 10.
The point cloud measurement data was compared with the model measurement data, and the difference value was calculated. The comparison results were shown in Table 2. The maximum error value in the table was -2.21 m^2, and the minimum error value was 0.52 m^2, which met the engineering requirements.
According to the basic data obtained from the modern and modern architectural metrology theory and model measurement, the calculation results of the brick quantity for the wall of Puzhou Drum Tower can be obtained as shown in Table 3 and figure 9.:

Drum Tower	Point cloud data measurement values （m^2）	Model measurement values （m^2）	Wrong Values （m^2）
E wall	101.55	103.76	-2.21
W wall	95.21	97.94	-2.74
South wall	80.23	79.71	0.52
North wall	88.6	90.08	-1.48

Table 2 Compare the original data with the measurement data of the established model

Drum Tower	Brick volume (m^3)	Brick thickness (m)	surface area (m^3)	Total volume of wall covering brick (m^3)	Amount of bricks used in shedding area (block)	The total amount of brick (block)
East wall	0.00138	0.78	103.76	80.93	58644	209962
West wall			97.94	76.39	55355	
South wall			79.71	62.17	45050	
North wall			90.08	70.26	50913	

Table 3 The amount of bricks used in the falling area of the wall of Puzhou Drum Tower

5. CONCLUSION

1) Puzhou Ancient City Drum Tower at the bottom of the package of the city brick most missing. The GEO SLAM handheld 3D laser scanner is used to obtain the data, and the Geomagic studio13 is used to conduct 3D reconstruction and measure the data to calculate the amount of bricks needed to repair the damaged area.
2) SLAM 3D laser scanning technology is applied to the protection and repair of ancient buildings, which not only reduces the workload of field work, but also has the advantages of high precision and high efficiency, which can completely replace the traditional surveying and mapping methods. In order to realize the digital protection of ancient buildings, a feasible technical route is explored.
3) In the Geomagic studio13 software, the data of falling off area of the outer wall of the Dum Tower model is measured. The falling off area of the east wall is 103.76 square meters, the falling off area of the west wall is 97.94 square meters, the falling off area of the south wall is 79.71 square meters, and the falling off area of the north wall is 90.08 square meters. According to the value of each brick is 0.00138 cubic meters and the thickness of the brick wall is 0.78 meters, then 58,644 bricks are needed for the repair of the east wall, 55,355 bricks are needed for the repair of the west wall, 45,050 bricks are needed for the repair of the south wall, 50,913 bricks are needed for the repair of the north wall, and a total of 209,962 bricks are needed for the

repair of the Drum Tower

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