SIGNIFICANCE OF DIGITAL RECONSTRUCTION OF HISTORIC BUILDINGS USING 3D LASER SCANNER CASE STUDY: PRASAT SUOR PRAT N1 TOWER, ANGKOR, CAMBODIA

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ABSTRACT:

A scanning device generally referred to as a "laser scanner", used to obtain 3D data of the objects by irradiating laser beams, is enjoying a steady rise in the number of users in the field of cultural heritages, as well as in other fields. This paper is based on an investigation and research to verify the effectiveness of the use of 3D laser scanners in order to obtain 3D information of historic buildings, taking up the case of Prasat Suor Prat N1 tower, Angkor, Cambodia. By using 3D laser scanners, it is possible to quickly preserve cultural properties with complicated shapes as highly precise 3D data, as well as to recreate the 3D image whenever desired, permanently, on the computer displays This is how expectations for the performance of 3D laser scanner have grown over the years, especially in the fields of cultural properties such as historic buildings, where accurate recording is the main concern.

1. INTRODUCTION

1.1 General

The dismantlement and repair construction of Prasat Suor Prat N1 Tower in Angkor, Cambodia has been enforced by the JSA (Japanese Government Team for Safeguarding Angkor) since the middle of September 2002. The tower is neighbouring a bank of a pond, and suffers the danger of collapse. The method for repair to be employed is to take apart all components and to repair the broken components and the foundation. Then these components will be assembled again to reconstruct close to the state of its founded period.
Before the dismantlement, the authors made laser scanning of the tower in order to obtain its 3D digital data for about two weeks in August 2002. Now we are able not only to hand the precious information accumulated for hundreds of years to the future generations, but also to deal with such space information easily on the computers.

1.2 About Prasat Suor Prat N1 Tower

Prasat Suor Prat is the name of towers that line along the Angkor *Thom's* Royal Plaza in the Angkor World Heritage site (*fig.1*). N1 is one of the twelve towers. These towers are believed to be built in the late 12th century by Jayavarman VII, who built many temples including the Bayon. N1 Tower is 18 meter high cylindrical tower with a chamber in front and an air well inside. It is built with reddish-brown porous blocks made of laterite and sandstone (*fig.2*).

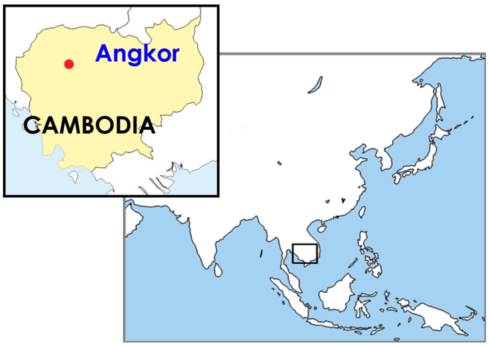

Fig.1 Location of Angkor, Cambodia

Fig.2 Prasat Suor Prat N1 Tower

2. PROCESS OF 3D DIGITAL ARCHIVES

2.1 The Laser Scanner

The laser scanner used for 3D measurement was Cyrax2500 made by Cyra Technologies. The specification is as follows.

Range measurement principle	Pulsed time of flight
Safety classification for scanner	Class2
Range	1.5m/50m, up to 100m
Range accuracy	6mm@50m
Field of view	40 x 40
Speed of measurement	1000 points/sec.
Operating temperature	0-40 deg.
Dimension	D401xW337xH238mm
Weight	20.5kg

3D digitization with laser scanning starts with the acquisition of a set of point with 3D coodinate data called point crowd data using the laser scanner. Cyrax2500 employs a measurement method called 'Time of Flight'. It calculates the distance between the scanner and the points on the object's surface based on the reflection time of laser beam. As the result, a set of 3D coordinates of points on the object's surface are obtained. Laser beam scans at high speed within the designated angle. The area measurable is visible area from the position of laser scanner. Therefore in order to obtain data of the whole surface of the object, it is usually necessary to conduct several to dozens, sometimes hundreds of scans from all around the object. Cyrax2500 is able to scan wide range, from short to long distance. In the case of Prasat Suor Prat, the measurement of the interior walls was from short distances of about 2m, and that of exterior walls was from long distances of more than 20m. In both cases, it was within the distance measurable (1.5-50m) by the scanner. Since the scanning angle is freely designated within +-40 degrees, the authors could make scanning following a detailed measurement plan with great efficiency.

2.2 The Measurement Method

Prasat Suor Prat N1 Tower is a large-scale laterite and sandstone made structure with a height of 18m. And there is an air well inside of the structure. In order to get the whole 3D data of the tower, it was necessary to build the scaffolds along the exterior and interior walls of the tower.

The measurement was conducted in four steps.

- Measurement of exterior wall using the outside scaffolds.
- Measurement of interior wall using the inside scaffolds.
- Measurement of exterior wall from the ground without scaffolds.
- Measurement of interior wall from the floor without scaffolds.

The scanning started with the measurement from the top of the exterior scaffolds around the tower (*fig.3*). Due to the high position, movements of the equipment were difficult works. In addition to it there was the need to make the measurements cautiously even under the intense sunlight because any slight movements of the scaffolds would make accurate data acquisition difficult. The measurement position was moved downward step by step, and the exterior measurement completed in about a week.

For measuring interior walls of the tower, scaffolds were assembled one by one level upward at a time in the air well (*fig.4*). It took about a week to reach the top of the tower.

All measurements were successfully completed in about two weeks and the 3D data of exterior and interior walls of the tower were obtained.

The total number of scan reached 473, and the authors have conducted data processing using 434 point crowd data which were effective among them.

Fig.3 Measurement from exterior scaffold

Fig.4 Measurement from interior scaffold

2.3 Data Processing

In order to make full use of the obtained 3D data for various purposes during and after the dismantlement repair construction, it was necessary to make the data accordance to the axis of coordinates which JSA had employed.

All data acquired were aligned with a software. In order to put these aligned data on the same coordinate system, the authors measured three concrete-made standard benchmarks around the tower by the laser scanner. By giving accurately measured 3D coordinates to the point crowd data of the benchmarks, all point cloud data were aligned on the coordinate system of the site. Then, the aligned point cloud data were merged with a software into a polygon data of the whole surface of Prasat Suor Prat N1 Tower (*fig.5*).

As the result, this data became corresponding to the ordinary coordinate axis, and the data became a widely useful basic 3D data for the comparison with the existing drawings which had made with manual measurements.

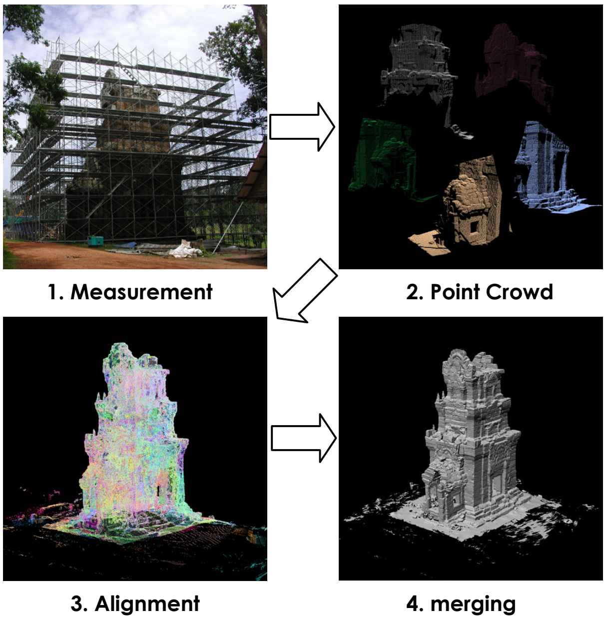

Fig.5 Data Processing

3. RESULTS OF MEASUREMENT

3.1 The Advantages and Disadvantages of Methods

The advantages of the measurement using the laser scanner are speed and accuracy. As the obtained 3D data can be displayed and viewed from any angle, orthogonal or perspective view as well as any cross-sectional lines are easily available (*fig.6*).
The disadvantages of laser scanning are a difficulty in automatic extraction and drawing of edges of component joints or uneven surfaces, and a difficulty in dealing with immeasurable part. It is also difficult to judge displayed lines on the 3D model if they are joint lines of components, cracks or surface patterns.

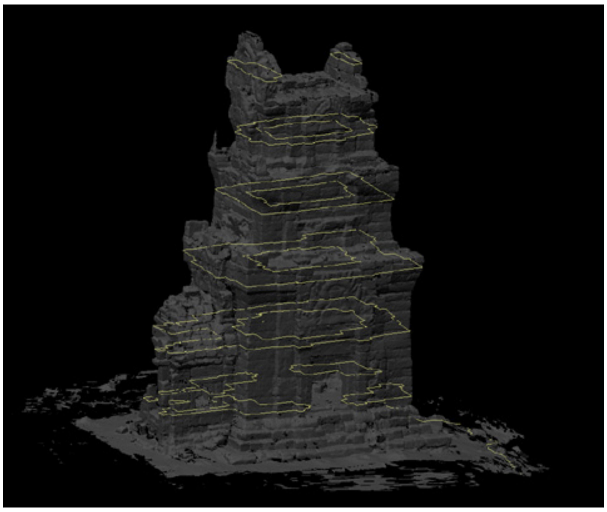

Fig.6 Drawing of Cross-Sectional Lines

On the other hand, manual measurement is inferior to the laser scanner in speed and accuracy. However, manual measurement and drawings contain necessary information made by specialists, though depending on who made them, they are useful in terms of correspondence to the purpose.

3.2 Further Development

In most cases the purpose of laser scanning is not making drawings with 2D lines but the generation of 3D data of the objects. When the laser scanner is used for the purpose of making conventional drawings, it sometimes occurs difficulty regarding the part where data could not obtained. Although the missed part is little and hard to find when compared to the whole object, it is necessary in order to make complete drawings such as plans, elevations, or cross-sections. Those drawings remain incomplete unless the missed data is supplemented and edited based on some grounds.
Therefore, accurate and speedy laser scanning is a very effective way for making drawings, ordinary manual measurement is also indispensable. It is important to increase the reliability of drawings based on advantages of both methods. The best way seems to be to make orthogonal drawings using 3D data of laser scanning at first, then to make survey and manual measurement referring to the orthogonal drawings and supplement lacking part or difficult part to recognize, and finish the drawings. Although there are problems to be solved including those of equipments, cost and labor, when such system has started to work efficiently, the results will be more than expected.

4. APPLICATIONS OF 3D DATA

4.1 Comparison with Manually Measured Drawings

The comparative verification of manually measured drawings and the 3D data obtained by laser scanning was conducted.
For a long period JSA has been educating Cambodian engineers as a part of historical conservation. In the restoration project of Prasat Suor Prat N1 Tower, the tower has been surveyed and manually measured by Cambodian engineers.

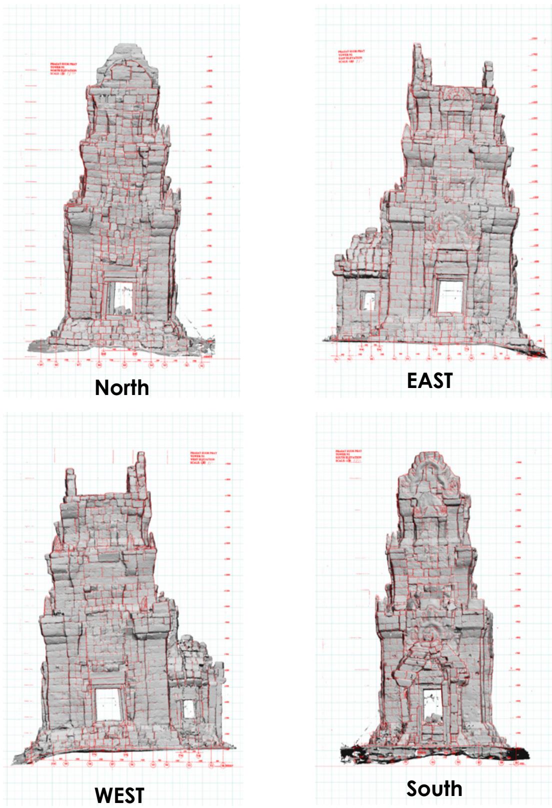

Fig.7 Superposition of Drawings

Presently all drawings including plans, elevations and cross-sections of the tower are completed. Those drawings were compared with the 3D data by superposition of both data. As the result, there were hardly errors between them in the form of the tower (*fig.7*).

4.2 Investigation on Inclinations

Using 3D data of the tower, the inclinations of the structure were investigated. First, the intersection of the diagonal lines of the structure's four corners of the same layer was identified and assumed to be the central point on the layer. Then, the central points of different layers were connected by lines, and their inclinations were defined as the structure's inclinations (*fig.8*). In the same way, ups-and-downs of corners on each layer were defined as that of the layer (*fig.9*).
As the result of investigation on the inclinations of 3D model, it was found that the tower is leaning toward northwest direction, which was the same finding by the verification of manual measurement conducted before (*fig.10*). The results of ups-and-downs measurement showed the numerical value mostly interlocked with the inclinations.
It is a valuable result that the same tendency of inclinations and ups-and-downs was found between different methods.

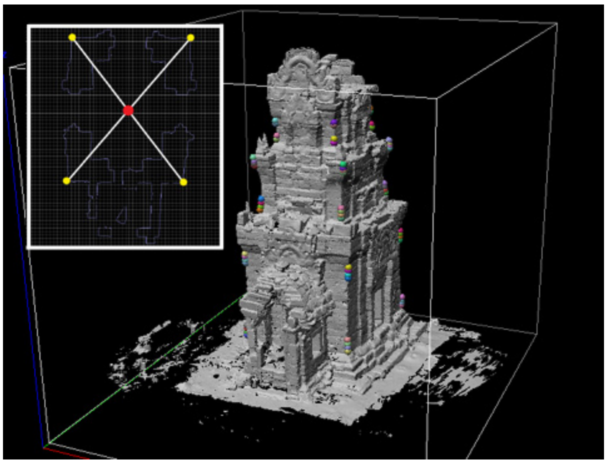

Fig.8 Selected Points on Four Corners

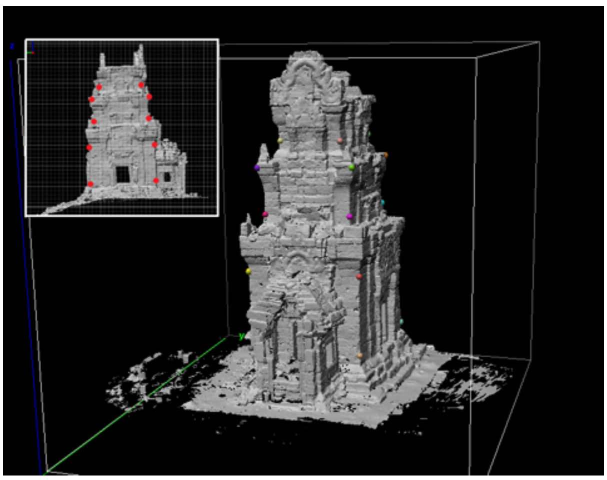

Fig.9 Selected Points on Junctions

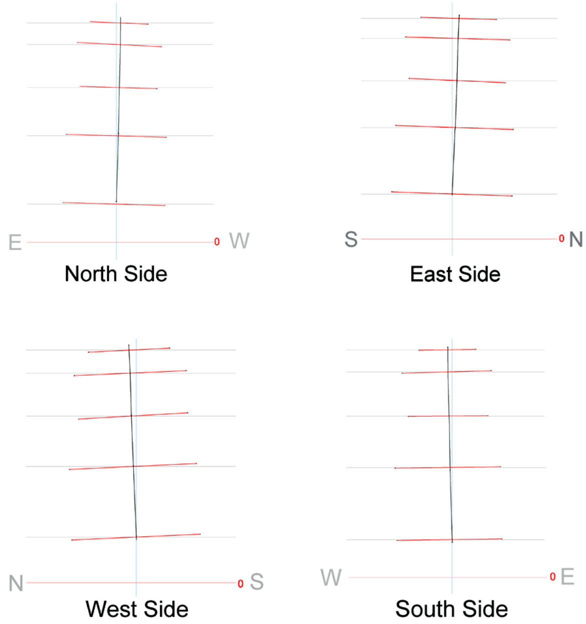

Fig.10 The Inclinations and Ups-and-downs of The Structure

4.3 Results

It was proved that laser scanning and manual measurement can supplement each other in order to increase the reliability of accuracy. By making use of advantages of each method, combined use of those methods will bring much more valuable and useful results.

5. CONCLUSION

Through the investigations, the effectiveness and the potential of laser scanning could be shown. It is also true to other cultural heritages in Angkor or similar cultural properties in the world. Moreover, it is also applicable to wooden or brick structures in general.
Prasat Suor Prat N1 Tower is one of the largest object among those measured by high-grade laser scanners, and it will be a pioneering example for the future measurement by laser scanning.
Laser scanning should not be regarded solely as the means of recording, but it should be widely applied to the development of 3D digital archives. Laser scanning will not only bring efficiency to conventional works such as making drawings and analyses of structures, but also make the management of whole attribute information such as components, breakage parts and repair parts possible.
Moreover, the laser scanning technology indicates various future possibilities in the conservation of historic buildings. The simulation of restoration using 3D data obtained by laser scanning will greatly advance the ways of restoration from conventional ones like models and perspective drawings. It will also provide a great visualization method when it is applied to virtual reality that can offer real-time change of views and free movement.
It is desirable that the 3D data should be obtained periodically in order to find changes in cultural properties, and the obtained data should be stored as a database so that they are available at any time necessary for various uses. The accumulation of the data will help restoration activities against unforeseen crises for cultural properties such as natural disasters.

Thus, the 3D digital archives using laser scanning has a great possibility to contribute to the conservation of cultural properties, and it is also a greatly effective way of conservation.

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