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Preservation of Historic Wooden Buildings and the Use of Digital Technology: An Introduction to Activities in Japan

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Abstract
This paper introduces the use of digital technology for the preservation of historical buildings in Japan (wooden temples and shrines). Important historical buildings are at risk of being lost due to earthquakes, fires and natural disasters. In 2019, Shuri Castle (wooden structure, UNESCO World Heritage) was destroyed by a fire of unknown origin. Due to the lack of records, reconstruction took a significant amount of time. The Notre-Dame Cathedral in Paris also suffered a fire of unknown origin, resulting in the destruction of its wooden roof. However, thanks to digital technology, the digital data was preserved, enabling a smooth reconstruction process. The construction methods of Japan's wooden temples and shrines are complex and manual surveys are time-consuming, costly, and prone to inaccuracies. By utilizing digital technology, measurements can be taken quickly and accurately.

Keywords
preservation of historical wooden buildings, 3D scanning, point cloud digital technology, photogrammetry, measurements by master carpenters

1. Purpose of the Study

The purpose of this study is to introduce examples of the use of digital technology for the preservation of historical buildings (mainly wooden temples and shrines) in Japan. Important historical buildings are at risk of being lost due to disasters such as earthquakes, fires, wind damage, and floods. In the event of such a loss, documents (drawings, photographs, etc.) are necessary for reconstruction. The use of the latest digital technology has made it easier to create such drawings.

Traditionally, surveyors measured structures by hands and created drawings. This process was time-consuming, and the accuracy of the drawings could be compromised due to the lack of skill among surveyors.

Recently, methods for surveying cultural properties such as historical buildings using digital technology have been established, and concrete efforts to create documentation are underway. This study aims to introduce examples from Japan and provide reference materials for the application of these methods in other countries.

2. Current Situations: Utilization of Digital Technology in the Preservation of Historical Buildings in Japan and Overseas

2.1. Situations in Japan

T&I Co., Ltd. (Ueno & Yoshikawa) conducted a survey of the ruins of a temple in Kumamoto Prefecture (southern island, Japan, Figure 1) in October 2022 and created a 3D model based on the survey results. In December of the same year, the Company further developed 3D modelling during a survey of another temple.

Furthermore, in February 2023, the company conducted surveys of another temple and traditional houses, creating 3D scans and point cloud maps.

Additionally, from June 2023 to March 2024, the company was commissioned by Eiheiji Temple (the Head Temple of Zen Buddhism in Fukui Prefecture, Japan) to create 3D scans and point cloud maps of the temple buildings and sculptures.

Traditionally, 3D measurement companies have existed for some time. These companies primarily focused on surveying civil engineering structures and conducting deterioration surveys of such structures, among other civil engineering-related tasks. Additionally, there were individuals who scanned small crafts and sculptures. However, those involved in the construction of traditional Japanese buildings, such as temple carpenters, rarely conducted measurements themselves.

A key feature of the team's technological development is that those involved in construction carry measurement equipment, assess the condition of buildings, identify key points to measure, and conduct surveys in dangerous areas such as attics and crawl spaces (below floors). This is a groundbreaking approach.

We conducted surveys and created drawings for most of the buildings designated as Important Cultural Properties by the National Government. The total number of buildings surveyed was 16.

Following this, we conducted 3D scanning and created point cloud drawings for approximately 10 temples and shrines designated as National Treasures or Important Cultural Properties.

From October 2022 to 2024, a total of 29 cases were completed.

2.2. Overseas Situations

There are many reported cases of 3D technology being utilized for the preservation of historical buildings overseas.

For example, activities involving 3D scanning and data digitization for the preservation of historical buildings in Italy are introduced in some papers [1, 2].

A panel discussion on the use of 3D technology was held in New York City. The following article introduces the event [3].

Furthermore, the use of digital technology is expanding into the field of urban planning. This is introduced in some papers [4, 5, 6].

In the medical field, digital technology is also being applied. In the United States, technology is advancing that allows patients' bodies to be 3D scanned and prosthetics and implants to be customized. This enables the provision of medical devices optimized for each individual patient [7].

As described above, digital technology is currently being utilized in various fields and serves as a valuable tool for research and planning.

3. The Necessity of Preserving Cultural Assets

Cultural properties are destroyed by earthquakes, fires, natural disasters, and wars (note that Japan has not been involved in war since 1945).

In Japan, the 2016 Kumamoto Earthquake (Note 1) caused partial collapse of the foundation of Kumamoto Castle (an Important Cultural Property) (Figures 1, 2). Aso Shrine (also an Important Cultural Property) collapsed.

In addition, in 2019, Shuri Castle (a World Heritage Site) on the southernmost island of Okinawa Prefecture was destroyed by a fire of unknown cause. There is little documentation on Shuri Castle, and its reconstruction is taking time. Reconstruction is scheduled to be completed in 2027 (Figures 1, 3).

Recent examples of damage: More than 400 traditional buildings were damaged in the 2024 Noto Earthquake (Figure 1, Note 2).

Note 1: Kumamoto Earthquake: April 14, 2016, magnitude 6.5, followed by a magnitude 7.3 earthquake on April 16, 2016. Kumamoto is a prefecture located in the southern part of Japan.

Noto 2: Noto Earthquake: January 1, 2024, magnitude 7.6, northwest of Tokyo.

In France, in 2019, a major fire broke out at Notre-Dame Cathedral in Paris, causing significant damage to the wooden roof. It was estimated that reconstruction would take 10 years, but the existence of “point cloud data” prior to the disaster enabled the data to be extensively utilized for swift reconstruction (Figure 4).

Michael Kimmelman wrote, “It is one of the timeliest and most uplifting outcomes of the restoration. It helped the restores that Remi Fromont and Cedric Trentesaux, two French architects, had taken precise measurements of the roof structure in 2014, and that Andrew Tallon, a Belgian-born Vassar College professor who died in 2018, had digitally scanned Notre-Dame before the fire, mounting laser scanner on tripods at dozens of different spots around cathedral, collecting more than a billion points of data” [8].

Eduardo Souza wrote, “We collected billions of points to capture every intricate details of the cathedral, from its vaulted ceiling to its iconic spire”, “the 3D model was used to guide the new design to honor its historic integrity”, “The 3D BIM model was the solution to challenge: its enhanced collaboration, clarity and efficiency across the reconstruction teams, was used to simulate and plan every phase of construction, and predicted issues that could arise before they occurred on the jobsite” [9].

By utilizing 3D technology and digitizing archives, it is possible to preserve the accurate current state for future generations. This is particularly expected for historical architectural cultural properties.

In the event of a disaster, it is essential to 3D scan buildings, obtain point cloud data, and preserve it (digital archiving) for the purpose of preservation, restoration, and reconstruction of cultural properties.

Fig. 1. Map of Japan [10]

Fig. 2. Foundation stones collapsed [11]

Fig. 3. Shuri Castle, Fire [12]

Fig. 4. Notre-Dame, Fire [13]

4. Advantages of Utilizing Digital Technology

The advantages of utilizing digital technology are as follows:

1. Effective for building restoration and reconstruction

In the event of damage or destruction of a building, restoration and reconstruction can be carried out quickly and effectively.

2. Reproduction of invisible parts

Even slight distortions in the structure of invisible areas such as above ceilings and below floors can be captured.

3. Precise restoration

Even if no blueprints remain, the structure of cultural properties can be precisely understood.

4. Non-contact survey of survey targets

When measuring cultural properties, photographs and measurements are taken from a distance, so there is no risk of damaging the cultural properties. In particular, when there are valuable sculptures, measurements can be taken without touching the valuable items.

5. Speed

By efficiently collecting building information through on-site measurements, we can quickly establish a plan on-site.

6. Ease of high-altitude surveys

Previously, high-altitude surveys required scaffolding, but by utilizing drones for aerial photography, surveys can be conducted without scaffolding. Scaffolding setup is time-consuming and costly, so this approach saves both time and expenses.

As described above, digital technology enables surveys to be conducted quickly, safely, and over a wide range, including high-altitude and invisible areas, with high-speed, non-contact measurement [14].

5. Digital Technology: Specific Equipment, Capabilities, Features, 3D Scanners, and Fixed-installation Devices

In one second, hundreds of thousands of laser beams are emitted toward the target object, and the position information is obtained based on the time and angle at which the light returns. The data formed by this collection is called a "point cloud". A built-in camera can capture images and assign colour data to the points. In high-altitude areas where lasers cannot reach, drone photography is used.

Photogrammetry (a technology that creates 3D models using photographs) (Note 3) or drones equipped with LiDAR (Note 4) can be used for laser scanning.

Note 3: Meaning of photogrammetry: " Photo" means "light", and "grammetry" means 'measurement' or "recording". Photogrammetry means "measuring and recording using light".

Note 4: Official English term and meaning of LiDAR: Light Detection and Ranging (LiDAR) is the process of measuring distances using light.

3D laser scanners to obtain precise location information, forming a collection of points in a three-dimensional space and converting it into 3D data. This allows cross-sections or planes to be created from any position. This technology operates on the same principle as medical CT scans, enabling quick detection of distortions, unevenness, or collapses in buildings.

By analysing photos taken from multiple angles, the shape and dimensions of an object can be accurately reproduced. This technology is widely used in various fields such as architecture, medicine, gaming, film production, and education.

For example, it is used for documenting cultural properties, reproducing the exterior of buildings, and creating large-scale 3D models of terrain using drones. The required equipment includes a camera, a computer, and specialized software.

Specifically, it involves emitting laser light toward an object, measuring the time it takes for the light to reflect back, and using this information to accurately measure distances, shapes, and terrain. LiDAR is used in various fields. Examples include surrounding detection for autonomous vehicles, 3D mapping of terrain, surveys of cities and forests, and archaeological surveys of ruins.

The purpose of laser scanning is to create drawings, restore structures, and facilitate construction. Its key feature is its high dimensional accuracy. The equipment used is a "laser scanner." Laser light is projected onto an object, and the resulting points form 3D data.

In the case of the Hatto Hall (Main Hall) at Eiheiji Temple, the number of points is 2,144,965,355.

Dimensions of the Hatto Hall: Height: 21.0 meters, Width: 32.2 meters, Depth: 23.3 meters.

In practice, backup data and data for specific areas are also collected, so the actual amount of data is approximately 3 to 4 times this figure.

The equipment used is as follows:

1. Laser scanner: Trimble X12
   - Acquires over 2 million points per second;
   - Supports long-range measurement up to 365 meters;

- Captures clear images even in dark areas;
- High-speed Wi-Fi (2.4 GHz/5 GHz) enables fast data transfer and operation of high-performance tablets;
- Manufacturer: Trimble, California, USA.

2. Drone: Mavic 3E
   - Mechanical shutter, 56x zoom;
   - Manufacturer: DJI (Da-Jiang Innovations Science and Technology Co., Ltd.);
   - Shenzhen, China, the world's largest drone manufacturer.
3. Software: Trimble RealWorks
   - Converts point cloud data into 3D deliverables quickly;
   - Software for processing and analysing point cloud data obtained from 3D scanners;
   - Point cloud data management and processing: Efficiently manages and analyses high-density, large-volume (millions of points) point cloud data;
   - Data synthesis: Integrates multiple scan data to create accurate 3D models;
   - Measurement and inspection functions: Features useful for quality control in construction sites and structures, such as face-to-face inspection, surface inspection, and wall verticality inspection;
   - Manufacturer: Trimble, USA, [14].

6. Measurement Flow

6.1. Flow

Step 1. TLS (Terrestrial Laser Scanner) type (Ground-based Laser Scanner) 3D laser scan preparation

- Select scan density, accuracy, and monochrome/colour;
- Set up position, tripod, ladder, stage;
- Building name, date;
- Point cloud data output size, scale selection.

TSL: A 3D laser scanner mounted on a tripod or similar device that emits lasers to acquire spatial position information of the target object.

Key features of TLS include high-precision measurement and the ability to acquire data over a wide area. Unlike traditional total stations (TS), TLS enables surface measurement, allowing for the rapid acquisition of detailed 3D data in a short time.

Step 2. Planning

- Position the scanner to minimize station overlap;
- Use indoor scanning in rainy weather;
- Scan areas along tourist routes during off-peak hours.

Step 3. Shooting

- Blow the laser emitter every 10 scans when outdoors.
- Blower: Regularly clean the lens to remove dust. Dust can cause noise, so keep the lens clean for high-quality data.
- Scan image diagram included (Figures 5-7), [14].

6.2. Point Cloud

Step 1. Point cloud data utilization methods and procedures

- Basic point cloud data;
- Acquire 3D coordinate values and colour data.

Step 2. Point cloud drawing

- Convert point cloud data into ortho-output drawings.

Step 3. 2D CAD data

- Convert point cloud data into vector data (CAD) drawings.

Step 4. Point cloud art

- Point cloud images, videos.

Step 5. 3D CAD data

- Modeling, CG creation.

Fig. 5. Preparation, Source: T&I Co. Ltd. Report

Fig. 6. Shooting, Source: T＆I Co. Ltd. Report

Fig. 7. Drone, Source: T&I Co. Ltd. Report

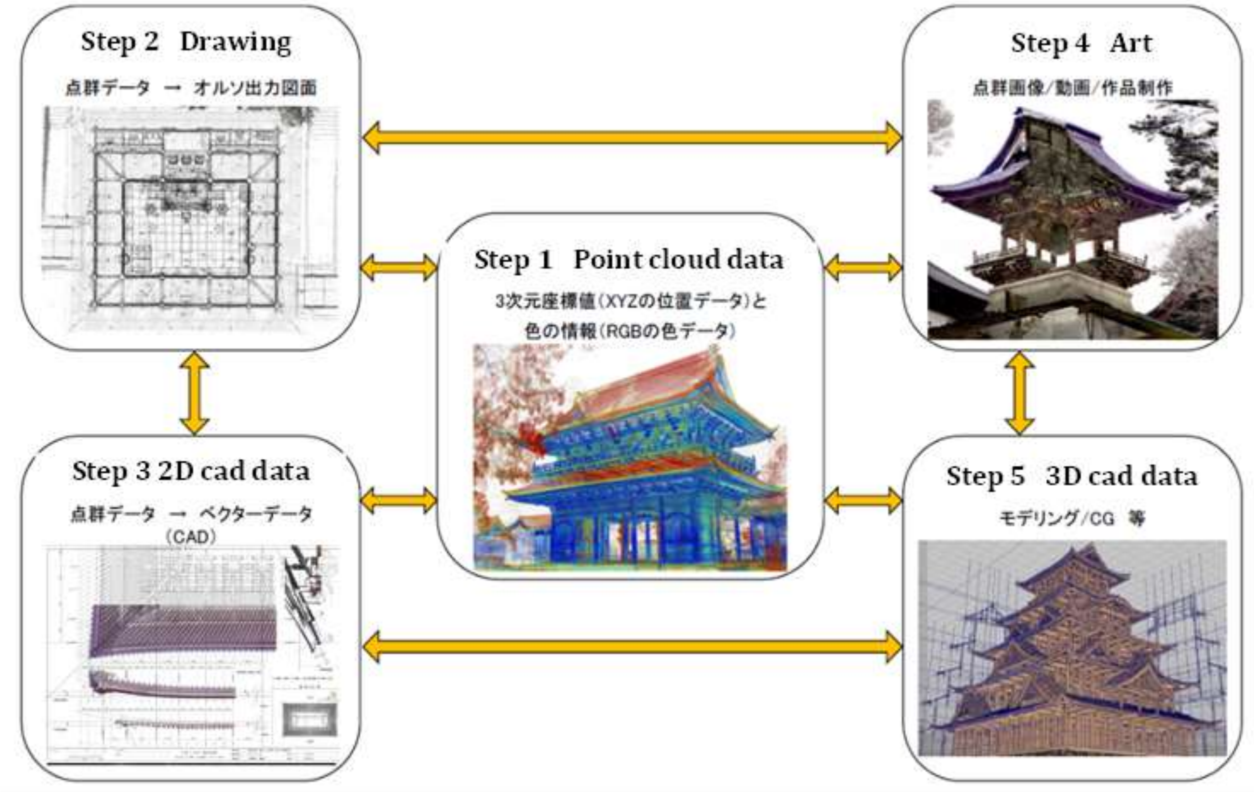

Fig. 8. Data Process, Source: T＆I Co. Ltd. Report

6.3. Orthophoto Features

Orthophotos are images that correct terrain elevation and lens distortion from aerial photos or satellite images to display accurate spatial relationships. This is created using a technique called "orthorectification". The characteristics of orthophotos are as follows:

- Distortions caused by terrain elevation differences and building heights are corrected.
- Maintains accurate position and size from a bird's-eye view.
- Used in Geographic Information Systems (GIS) for measuring area and distance.

These technologies are widely used in various fields such as urban planning, disaster prevention, and environmental protection.

Parallel projection

A projection method that assumes all light sources are parallel when projecting an object. This ensures that the shape and dimensions of the object are accurately preserved.

It is commonly used in architectural drawings, mechanical design, and other applications requiring precise dimensions [14].

7. Issues

The following are the issues and prospects for the future.

Shrine and temple architecture was constructed using the most advanced technology of its time. The continuous innovation of that era has become "tradition" and has been passed down through the generations.

When dealing with traditional architecture, it is essential to clearly distinguish between what must be changed and what must remain unchanged in response to changes in the times, and to engage with digital technology.

By respecting tradition and utilizing modern digital technology, we can contribute to the development of Japanese culture. Additionally, by leveraging this technology, we can play a role in preserving historical buildings worldwide for future generations.

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