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3D Scans for Weather-damaged Sculptures

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ABSTRACT

The creation and maintenance of different kinds of authenticity is explored for the preservation of weather-damaged sculptures. This is a one-year cultural heritage preservation project led by Juming Museum, to scan stone and copper sculptures by the famous Taiwanese sculptor, Ju Ming. Two approaches were applied to the sculptures. They were based on the use of suitable scanners for the different materials, sizes and conditions, as a way to extend previous studies and facilitate future research. The scanned 3D data led to the identification, inspection, quantification and comparison of deteriorated and damaged parts. By combining existing procedures and minimizing the learning experience for museum researchers, this project not only prepares geometries of different resolutions to make the transfer of the model's data proceed smoothly, but also recommends the virtual tools and setting for research-related work.

Keywords: 3D laser scan, cultural heritage, historical preservation, Ju Ming.

1. INTRODUCTION

Heritage preservation is a project which integrates planning, design and resources [7,12]; it involves many roles, from data acquisition to web page creation [6]. As all maintenance efforts need to be planned ahead, information should be in the simplest possible digital format to minimize the need for specific, or possibly obsolete, software [7].

Experience with buildings can also be applied to heritage preservation in terms of data management and inspection. In addition to the 3D geometric data, a large amount of heterogeneous data is collected and generated during the analysis of buildings. Integrating diversified data types requires managing the collected information in regard to structural inspections, as well as the measurement, analysis and interpretation of building shapes [2,5,10,11].

The public needs access to cultural heritage subjects over the web with real time interactions [8, 14]. The results must also be presentable for large audiences and pedagogical purposes in the virtual world [1,3]. This project was conducted outdoors, where daylight variations were a great concern, as opposed to those scanned in a lab with controlled lighting [12] in the virtual world.

1.1. The Background of Ju Ming

Ju Ming (Fig. 1) was born in 1938, and is one of the foremost artists in contemporary Taiwan. He was trained in traditional crafts, and is regarded as a symbolic figure in the Taiwanese Nativist Movement of the 1970's. He impressed audiences with his first solo-exhibition in March 1976 at the National Museum of History, and won critical acclaim from local artistic circles when his works were displayed at the Tokyo Central Museum of Fine Arts in Japan, and in the Max Hutchinson Gallery in New York City. His creative output increased extensively between 1980-90, with his work being exhibited in Singapore, Hong Kong, England, France and Japan. He has been awarded the Chinese Arts Association's 17th Arts Medal, the 14th Top Ten Outstanding Youths Award, the 2nd National Arts Award, an Honorary Doctor of Arts, the National Cultural Award of the R.O.C. in 2004, as well as the 18th Fukuoka Asian Culture Awards, and the Arts and Culture Award.

Ju Ming claims that one does not need to think during the creative process, nor should one need to. The absence of thought maintains the work's simplicity, because only then can it be directly expressed. Abstaining from thought protects the integrity of a

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Fig. 1: Ju Ming and the transformation of a two-person confrontation, as in two separated subjects, into an integrated form (from left to right, top to bottom), which defines different levels of interstitial spaces from explicit presence to none.

work without intrusive, abstract thoughts marring its essential nature.

Ju Ming's artistic career can be divided into three stages: the "Nativist Series", the "Taichi Series", and the "Living World Series." His works began to demonstrate more self-expression and spirituality with the Taichi Series, which grew out of body and movement. His sculpting tools are wielded more according to "will" than to "form", and "not just capturing specific Taichi movements, but also the transitions in between" (Fig. 1).

1.2. Previous Museum Research Studies

The purpose of artwork conservation is to preserve a work's current condition with the least possible intervention. The deterioration (in the form of detachment, breakage, scaling etc.) of outdoor stone sculptures is a natural phenomenon, and continues regardless of conservation efforts. However, the speed at which artworks deteriorate can be delayed through conservation methods and, ultimately, they can be preserved. Weather and air quality monitoring data provide vital information for rock weathering studies; therefore, direct and non-contact monitoring was utilized in this project to obtain first-hand information for the configuration study and analysis.

The Juming Museum has conducted a series of studies regarding environmental effects and sculptures' physical reactions to weather. The museum is located in the northern shore of Taiwan (Fig. 2) on a windward hillside that directly comes in contact with northeastern monsoons. The climate is not only humid and wet, but the region is also exposed to high levels of pollutants carried over from mainland China by these monsoons. Also, the sulfuric gases emitted by Datun Mountain (active volcano) react with moisture and atmospheric substances to produce sulfites and sulfuric acid, all of which lead to the acidic erosion of outdoor sculptures. The museum is in close proximity to the ocean, and the high salt content in the atmosphere also leads to the deterioration of its artworks. The sulfuric and nitric acids that are present in acid rain dissolve the calcium in stone, causing the surfaces to roughen and carvings to fade gradually.

Water content encourages biological activities and causes physical and chemical damage to rocks; water's dissolvable salts seep into rock fissures via capillary action. Any of the following processes can increase pressure levels within the rock fissures: 1) salts absorb water and lead to a rise in volume, called water-filled pressure; 2) salts lose their water content and crystallize; and 3) increased crystals produce pressure on the area in which they are deposited. The sources of these salts can be: atmospheric pollutants, sea salt, acid rain, or soil and groundwater capillary action. Long-term exposure to a humility environment leads to continuous salt reactive processes, causing the rock to deteriorate.

2. TAICHI SQUARE & STONE CONSERVATION LAB

This is a one-year scan project (2011.4 – 2012.5). The involved target sculptures are divided into two themes according to grouping, materials, locations, and the period when the work was created (Fig. 2):

- Taichi Square: a total of 8 sculptures were scanned. The "Taichi Series" emphasizes the subject's body and movement. The original molds of these cast copper alloy sculptures are made of Styrofoam which is carved and chopped with electric saw to create the abstract form and rough texture. The forms and details differ drastically in size. Scaffolds were erected to scan the topmost portions of the larger pieces. Although a uniform dark color was initially presented, the colors on top have faded due to sunlight and accumulated dust. The scaffold is

Fig. 2: The sculptures, museum map [9] and the location.

equipped with larger member section for better lateral and diagonal support. For a vibration-free result, no workers were allowed on the scaffold while the scanner was under operation. A long-range 3D scanner, a Leica HSD 3000® (300 meters with 90% reflectivity) was used to retrieve geometric data and the corresponding software, Cyclone, was used to register scans and paste photo images.

- Stone Conservation Lab: complex details on the body and surface are presented. The entire collection consists of 30 works ranging from 50 to 200 cm in height. The largest piece is a sculpture cluster of 27 close-set units. The single components are smaller and more uniform in size, but in most cases, a ladder was used to scan the topmost portions. The colors differed drastically due to environmental lighting conditions and the different levels of rainwater infiltration. Deterioration was rapid and visible. A short range Artec HM-T® hand-held 3D scanner (30-120 cm) was used for the geometric and photo-realistic color texture retrieval (Figs. 3& 4).

The stone sculptures have different expressions. As Ju Ming stated: “stone sculpture has life.” The expressions usually come from changes in appearance caused by environmental factors during various weather conditions. Scan results have recorded dozens of expressions altered by light, rain, configurations, and color.

- Light: compared with an indoor setting where light direction and color temperatures are

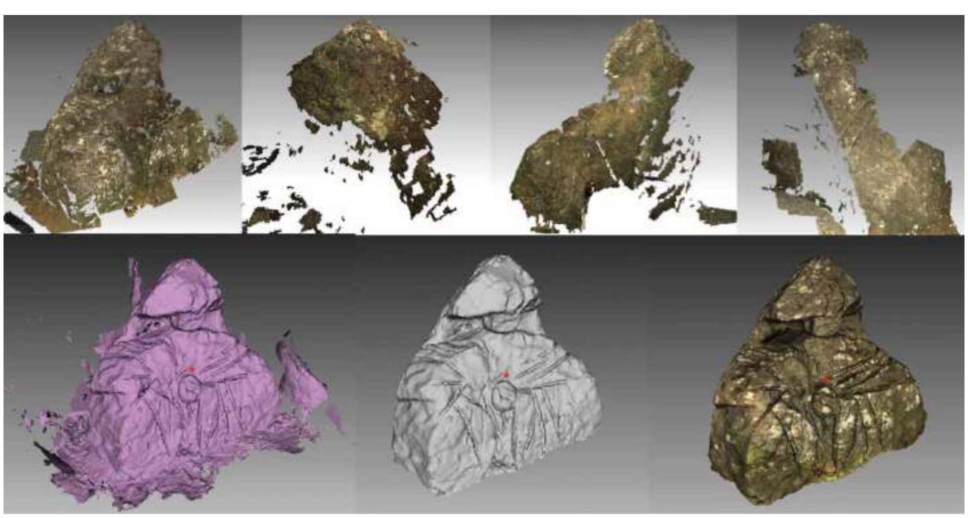

Fig. 3: Individual scans (top), registered object, and texture mapped result.

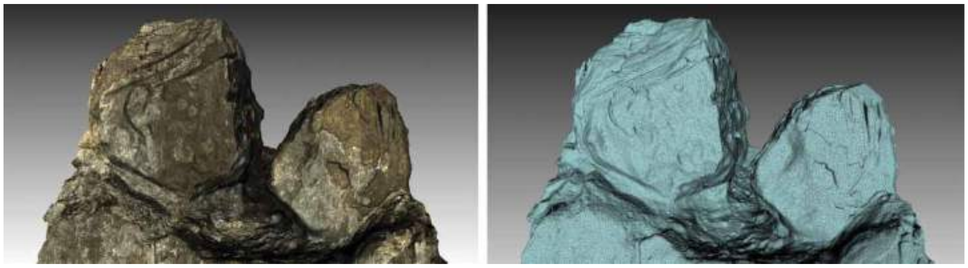

Fig. 4: 3D scanned data with image mapping and in full geometry resolution shown in high density mesh (over 7,000,000 polygons).

controllable, this project was conducted outdoors, making the control of light and shadow more difficult. For example, time lags existed between the scanning sessions, and even between each session's start and finish. Color correction, which is usually applied under fixed conditions that surround and influence the main subject, may have been changed by a shadow's shape and location. The corrected results may not be exactly the same. Since multiple scanners are not simultaneously available, a practical method is to mix the overlapping areas to smooth the color transition. The final presentations come from a blend of long-term scans.

Nevertheless, debate exists regarding under what situation a sculpture should be presented to public: no shadows like in an indoor museum or with shadows in a field just like in a sunny day to match daily visual experience. Both situations applied in the project, as the shadows appear to some Taichi Square sculptures.

- Rainwater: The presentation and recording of weather were conducted in specific regions. The local climate is humid, so the sculptures were frequently covered with a thin membrane of water. Rainwater was present on sculptures in different areas, under diverse levels of infiltration. The differing depths of surface water led to darker tones and reflections. To expedite the project, scans were usually made the following day after the weather had cleared, when some sculptures still had water accumulations in cavities, and surfaces were partially wet. To illustrate the visual contrast between wet and dry surfaces, the effect on these materials was studied by combining the scanned model with the photos taken on wet and sunny days, respectively (Fig. 5). According to the monochrome model, after the textural colors were removed, small amounts of water remained at the bottom of a diamond-shaped concave. The foreign substance is shown visually, with the transparent water remaining in the image.

  This is a very unique observation; it can extend the recording capabilities of different surface characteristics, and actually help us to understand the preserved object under contrasting conditions. While various parts of most sculptures were recorded under similar conditions, a special method was adopted to illustrate how the changing local climate can cause specific parts of the same sculpture, where the most severe infiltration actually occurred, to have different appearances.
- Deterioration: environmental factors changed the sculptured surfaces, usually through peeling or partially embedding them in the soil. Examples are given in the Section 5 for the scan verification of weathering deterioration in sculptures.
- Color: although the copper sculptures have monotone patinas which were created by the artist, their appearance still vary with the daylight conditions (sunny, overcast, or rainy days),

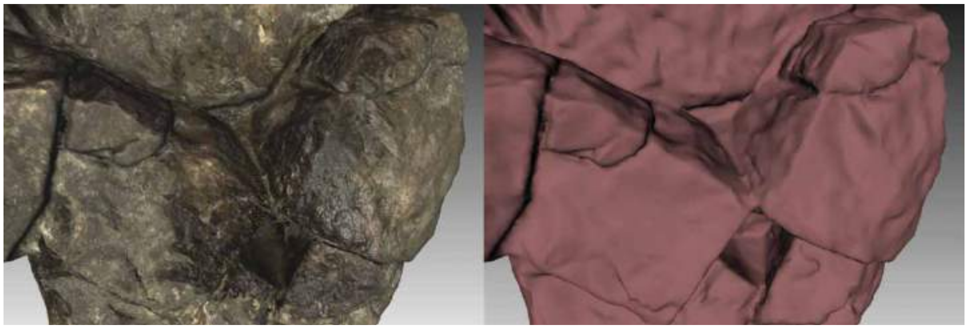

Fig. 5: The presentation and recording of how water affects the surface of a specific sculpture.

environmental projections (from lawn, ground, trees), dust, surface reflections (when dry, moist, wet), or verdigris. In order to quickly response to the daylight variation, a photogrammetry approach was applied and to be mentioned in the Section 6: 3D auxiliary construction and recording tool.

3. SCALED-DOWN GEOMETRY FOR PRESERVATION REQUIREMENTS AND PRESENTATION

The original scan results are archived. Nevertheless, file size increases with the object dimensions and scanning resolutions enlarged. The dimensional changes are greater with the copper sculptures, by up to about 20 meter, compared to the stone sculpture's range of 50-200 cm. Although the hand-held scanner provided higher resolutions for a much better model quality, it was rather difficult to scan the large copper sculptures with the limited scan range and potentially outnumbered registrations. Unless the subject size is smaller than 2-3 m and the potential registration number is more than 50, a long-range scanner was used for the larger copper sculptures, and the individual ones in the group were scanned separately.

The key issue that the 3D scans and webpage models had to take into account was the size of the details on the entire sculpture. In case there are insufficient details shown when browsing all the models, the file size has to be well tested in order to balance the browsing speed and the perception of real world details. For example, the copper sculpture casting process resulted in pluck marks on the Styrofoam. After reducing the original scanning data in the first stage, the original 3D model was reduced to a reasonable file size in order to clearly display the sculpture's wrinkles, marks, or edges. As the volume increases, details on a scaled model were not easily recognizable, so additional image mapping was used to enhance the visual details (Fig. 6).

The stone sculpture area was scanned three times to compensate for an omission from the last visit or to increase the resolution of details. The principles by which to process the initially captured data are subject to digital preservation requirements, the presentation effect and decimation.

1. Preservation requirements: form and texture were simultaneously taken into account. For example, the normal-sized sculptures in the stone sculpture area required about 100,000 polygons to display the gouge marks. Therefore, 100,000 polygons became the basic reference; empirically, 10,000 polygons constituted the web presentation's benchmark. With the assistance of mapped images, the clarity and speed were balanced. In the case of the copper sculptures, 5000 polygons became the required

Fig. 6: The control over the resolutions of the model.

benchmark; the photos were mainly used to assist the visual representation of the geometries.

2. Presentation effect: the texture's file size was also reduced to lower the overall size for web display efficiency, with the original image texture generated by the scanning program. After the geometries were reduced, most of the object's surface textures were changed into textile with a higher contrast. Although the contrast helped with feature recognition, sculptures are still visually different from their on-site appearance. This study applied the Gaussian blur (radius parameter 0.5) to reduce the contrast.

   When rapid prototyping (RP) models are printed in a smaller size (1/20), details cannot be presented unless texture color is applied. Therefore, the requirements for the webpage presentation and RP output in this case are relatively similar for browsing efficiency and display effectiveness. The final file size for the Taichi Square's 3D web page had a total of 19MB, or about 1.2MB per piece. The stone sculpture area has a total of 82MB, or about 1MB per piece.

3. Decimation: reducing the scanning results to meet the requirements of the web presentation is a planned, all-consuming task that has to be completed in stages by separating the geometric object from the image files. In the first stage, scanner software was used to reduce the data to 1/15-1/20 of the original polygon number. In the case of an OBJ file conversion, the texture's file size increased substantially because the original, individually scanned images were merged and converted into a series of tiled image maps. The second stage was implemented using Geomagic Studio® or Meshlab® software; the former is limited in its reduction proportions, but the latter has larger flexibility. For example, take the sculptures in the stone sculpture area: the final 3D web page model of No. S2 had polygons reduced to 1/155 of the original numbers. The new OBJ file, containing the original geometric object and image, is about 576MB. The size was then reduced to 34.9MB (in 100,000 faces), and the file size in the webpage presentation is about 1.4MB. The overall size of the three file types was reduced to 1/411 of the original (see Tab. 1) with the geometry-related file being reduced to 1/472.5, and the image files being reduced to 1/427.5. The scaled down proportion for the large sculptures (P1) reached a ratio of 1/740 (Fig. 7).

   At first, the original mesh was decimated with the size or resolution of mapping images

		P1			*S2*		
		geometry	*image*	*geometry + image*	*geometry*	*image*	*geometry + image*
sculptures		obj		html, dae, jpg, swf / obj, jpg, mtl	obj		html, dae, jpg, swf / obj, jpg, mtl
ratio	10000/100000 polygons	*1/28* (0.658MB /18.24MB)	*1/21* (0.877MB /18.37MB)	*1/18* (2.04MB /35.7MB)	*1/28* (0.628MB /17.85MB)	*1/26* (0.669MB /17.06MB)	*1/25* (1.38MB /34.9MB)
	10000/1550000 polygons	*1/1193* (0.658MB /785MB)	*1/920* (0.877MB /806.9MB)	*1/740* (2.04MB /1510 MB)	*1/473* (0.628MB /296.8MB)	*1/428* (0.669MB /286MB)	*1/411* (1.38MB /576MB)

Tab. 1: Scale-down proportions of a large stone sculpture (P1) and a normal-sized one (S2).

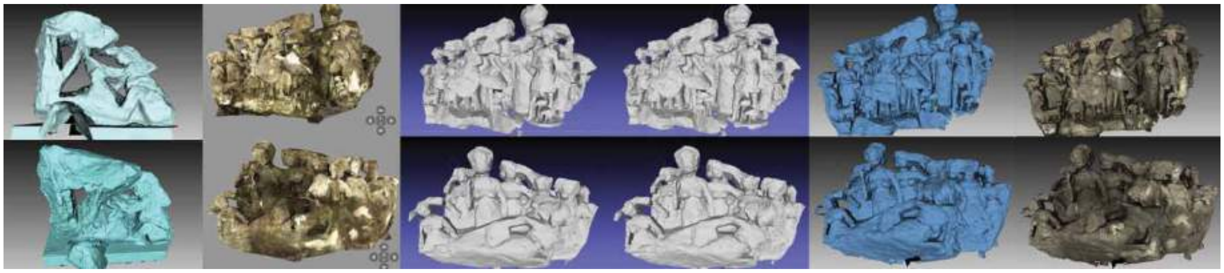

Fig. 7: Different sculpture decimation levels: S2 (left, 10000 vs. 1550000 polygons) and P1: web (2nd & 3rd columns), 100000 polygons (middle), and full with 80 scans (right two rows).

at the same time, then the images were reduced separated. For example, sculpture P1 was decimated from 17 jpg files of 806.9 MB to 1 jpg file of 18 MB, then to a jpg file less than 1 MB. For geometries (polygons), both the curvature priority and the polygon count were employed. Although the former can maintain more details, the small number of polygon count usually eliminates most of the details.

4. INTERFACE FOR VIRTUAL WORLD AND PHYSICAL SUBJECTS

For promotional and inspection purposes, the web pages and RP models are used as “interfaces” for the virtual 3D model. The original 3D models are the core data that are stored separately for internal use, and cannot be modified. Data that used to be retrieved only by researchers are now accessible to the public. A user can use the two data types as an index to pinpoint, reference, and communicate a specific region of interest.

The webpages are linked to the museum’s existing website. The two sections of the webpage are designed with similar requirements and purpose, and are viewed using similar elements (Fig. 8). The pages were built with Tourweaver® customized interfaces.

- Panoramas: the number and locations of the panoramas are designated, based on the museum’s zoning. There are two sections, each consisting of 5 scenes, for a total of 10 panoramas. The location of each panorama takes into account the presentation of the sides and base of a large object. The sculpture cluster has a specific link to an enlarged photo to facilitate the identification of each piece’s relative position. Each panorama has individual links to activate the 3D object’s pop-up window.
- Objects: there are 30 sculptures in the Stone Sculpture Area. There is an additional cluster consisting of 27 sculptures (some of them contain 2-3 components) for a total number of more than 60 sculptures. Each sculpture has a 3D digital model that can be rotated and zoomed. The models were converted from Artec Studio®, 3DS MAX® with the Swift3D® plug-in, to a Papervision 3D® project (with Collada file in .dae). After Flash® conversion, the final set of 3D models consists of several files, such as an index.html, a 3D.html for defining the object and text window size, a 3d_t.html for text descriptions, a DAE file for the model’s data, an SWF file for the model’s interface icon for rotation and zooming, and a JPG file for materials. The Flash-based object can be browsed without using a pre-installed special plug-in. The same Flash file set can be directly viewed with rotation and zooming on an Android phone (version 4.0.3) using SWF Player® (Fig. 9).
- Hotspots: sculptures are linked by hotspots and highlighted by clicking on the mouse, with pop-up information. After browsing, the hotspot is then highlighted as history. The Taichi Square uses polygon hotspots with the same boundaries as the copper sculpture. The stone sculptures are highlighted by using unified symbols

Fig. 8: Illustrating interactive digital data in a 3D web virtual environment through panoramas and models.

Fig. 9: Rotation and zooming of 3D sculpture by Android APP.

to avoid selection difficulties caused by the subjects' overlapping boundaries.

- Introductions: available in both sections. When the mouse is moved over a sculptural image, pop-up pictures of texts and images appear. With a mouse click, the textual introduction is shown on the right side of the 3D object's pop-up window.
- Value-added links: a web store appears, along with the 3D object's pop-up window, under the Introduction.
- Map: is made from the museum's map and located at the bottom-right of each panorama. In addition to presenting the panorama's location and viewing angle, it can be directly clicked into a corresponding panorama.

The RP output of the entire sculpture cluster was a challenging process, especially in defining each individual shape and its relative location. The cluster model needs to print about 30 RP models. After the scanning and registration of the 3D models for individual sculptures, the data for the RP model were basically completed (Fig. 10). To fully define the geometric interrelationship, scans were made by a long-range scanner from different viewpoints to cover the entire region, but the plans, elevations and sections were produced afterwards. These drawings helped to confirm the model's base.

One of the empirical findings was that the sculptural arrangement had too large a gap; it might lead to distortion after viewing the final RP set from the top. One assumption is that the different perception, from the on-site appearance, comes from the relatively high bird's eye view. This is in contrast to a visitor's viewpoint, which is lower, and results in an overlapping vision with a limited depth of field. Another assumption is derived from the visual focus of the 1/20 scaled RP model. Compared to the overall appearance of the cluster, the RP output highlights the individual appearance, thus making individual differences even more significant than the gaps in between. This

Fig. 10: Illustrating digital data by scaled physical models which are 3D-printed using a RP machine (Microjet®).

experience was constructive, as the perception uncertainties led directly to an investigation of the cluster's composition.

5. SCAN VERIFICATION OF A SCULPTURE'S DETERIORATION DUE TO WEATHERING

Both virtual and physical models were used to inspect the rock deterioration caused by physical (granular disintegration, block disintegration, and exfoliation), chemical, and biological weathering. The detailed scan records helped with the identification, quantification, matching and comparison of the deterioration and stress damage. The records showed old surface characteristics as well as the location and scope of the new conservation. Since this is a one-year project, previously scanned models were used as a basis for consequent monitoring.

Comparisons were made between changes that occurred within this one-year period; to achieve this, the model's chronological records were aligned to mark specific changes in terms of location and boundaries. This is an easy and straightforward method of displaying newly occurred changes. For example, the matching and comparison of the changed landscape with the main part of the sculpture showed a 1/4 of a specific sculpture buried under newly renovated grounds. Cracks caused by rock stress are also shown. Cases of weathering include Nos. 3, 6, 7, 11 and 13 (head divestiture), 15 (partially buried), 17 and 18 of the individual stone sculptures, and 3, 4, 23, 25 and 27 of the sculpture cluster (Fig. 11). A similar effort was conducted on Easter Island [4]. One of the major differences is the application of hand-held scanners to record the much more complicated details and configurations of sandstone sculptures. The fast registration without any targets is also very helpful in

Fig. 11: Cases of sculpture deterioration.

Fig. 12: Original photo, typical texture mapping, and the manipulation of display variables.

avoiding any possible contact with the sculpture and nearby objects.

An additional method used was Geomagic Qualify® to align photogrammetry and 3D scanned models, where variations of different parts highlighted in terms of RP outputs, were also used for comparisons. Aligning models with the same output actually shows the relative location and different shapes.

Upon inspection of the sculptural surface, the monochrome mode is as important as the color mode. As the object's surface is color-textured, judging the subtle concave-convex details can be difficult with a virtual display, whereas it is relatively easy to judge such details in the physical setting. Without the help of appropriate visual factors like an auto-stereoscopic display (ASD), the concave-convex details are alternatively inspected either in monochrome or mesh mode (Fig. 12), while parameters, such as gamma, are also adjusted to study subtle weathering damage in color.

6. MUSEUM RESEARCHERS' VIRTUAL TOOLS AND WORKING ENVIRONMENT

Life-cycle maintenance needs to process data from the initial concept development (scaled study model), the working artifact, to the completed artwork. In the event of possible findings discovered during scanning, these changes should be recorded for any future work that might eventuate. Therefore, a working environment is proposed for the museum researchers, along with a suggested auxiliary recording procedure, for periodical inspections and casual incidents.

This project recommends a working environment and software for internal inspections and research, for: 1) the smooth transfer of the model's data to the researchers from the museum unit that commissioned this project; and 2) a direct combination of existing procedures to keep the learning load to a minimum. In-museum model browsing, this project used an OBJ file for browsing; plug-ins such as Cortona® or Otaga® were also used. However, VRML

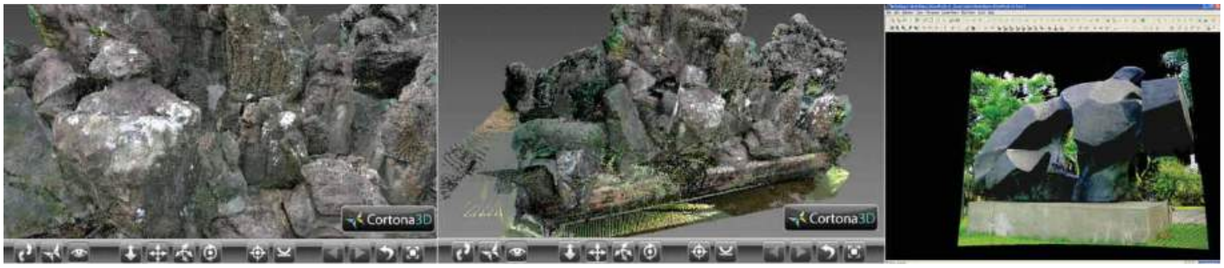

Fig. 13: Alternative interface for 3D models: browser mode (left, middle) and Cyclone® application mode (right).

Fig. 14: Photogrammetry creating process (left), 3D model (middle), and the comparison with the model created by 3D scanned data (right).

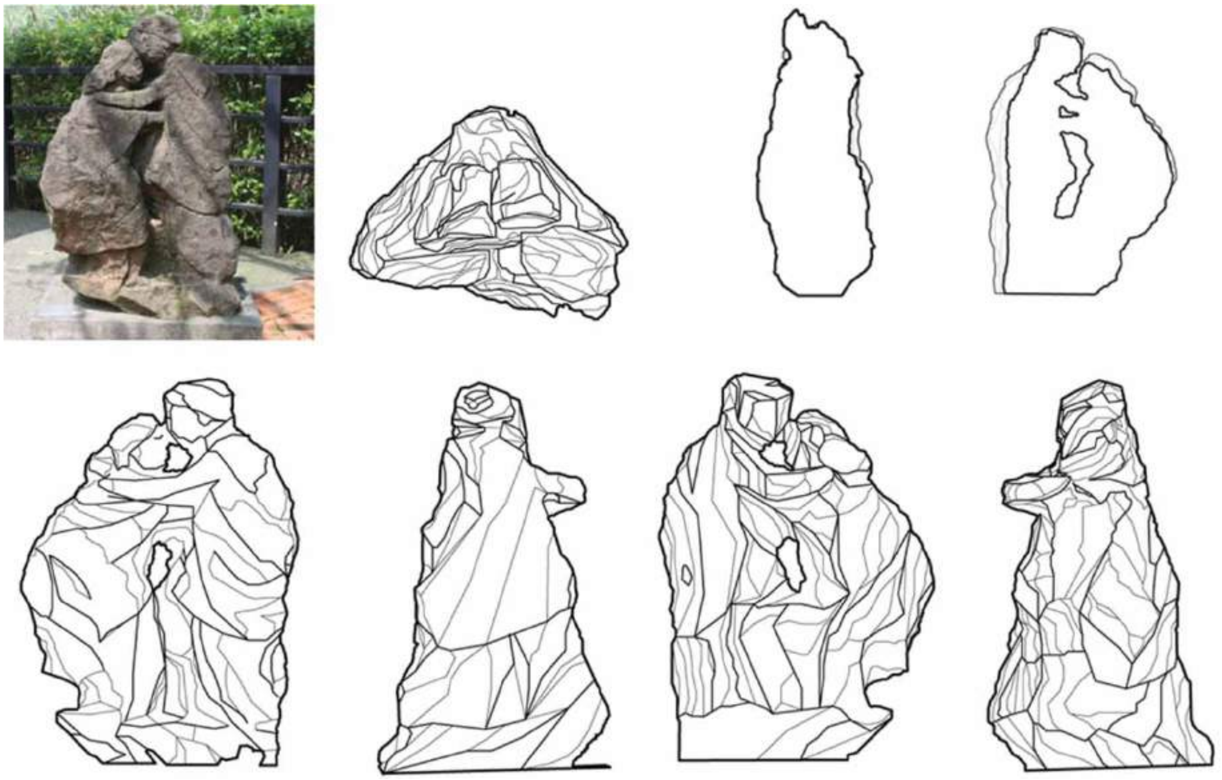

Fig. 15: Drawings of plan, elevations, and sections.

or X3D format have been suggested as alternatives, along with other compatible platforms for in-museum browsing of large point cloud files (Fig. 13).

3D auxiliary construction and recording tool is also recommended: a digital camera, coupled with photogrammetry programs (e.g., 123D Catch® in this case) be used on the site to immediately record images from all directions, and construct a 3D model (Fig. 14), particularly in order to quickly respond to the daylight variation which is mentioned earlier in the Introduction. Traditional drawings of plans, elevations and sections are still prepared in AutoCAD® for documenting purposes (Fig. 15).

The scan data was found to be useful in estimating the weight of each copper sculpture which was already fixed in the field. The sculptures are hollow inside and are cast in the same manner. With only one sculpture's weight known, the estimation was made based on the skin area above ground level in proportion to the known one. Two versions of material volume were calculated. The first one was 0.166316 m^3, of which the known weight (1422 kg) was divided by density (8.55 g/cm^3 – Copper + Zinc). The second one was 0.1442245 m^3, of which the shell area (28.8449 m^2) was multiplied by the designed thickness (5 mm). After multiplying density, the latter is about 15.3% lighter than the former. Nevertheless, an increase of shell thickness to 5.7 mm would reduce the weight difference to only 1.15%. For a sculpture this thin, a minor difference in cast control or area estimation may increase or decrease weight estimation dramatically.

7. CONCLUSIONS

By applying two different scan approaches to the two types of sculptures, multiple levels of reality were explored in terms of material, size, complexity, and weather conditions. This project stands out from other local digital preservation cases, where data were the display-oriented turnkey result, with the extended scope of planning, applications, and promotional interfaces. In addition to integrating preservation plans, designing, and resource management, this project has solved problems caused by extensive variations in scale and mutual obstructions. The sculptures' different appearances are also explored to facilitate inspections in both the virtual and physical settings. With regard to concerns about the adaptability and convenience of the new working environment, simple tools with extended functionalities were applied to a feasible example of the researchers' cultural heritage preservation work.

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