A Practical Approach to Ascertaining the Accuracy and Resolution of Post Rendered 3D Models Acquired Originally via 3D Digitization

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Abstract. 3D digitization is becoming the norm in the preservation of tangible cultural properties be it movable or immovable. In the case of mobile cultural objects, 3D models are normally acquired through non-destructive methods such as photogrammetry or 3D scanning using structured light or laser. The continuing improvements in scanning equipment which result in higher accuracy and resolution can be translated to mean higher level of 3D data acquired. At times, the quantity of 3D data of a single model can get too large and beyond what a normal workstation can process. This is where optimization comes in. However, the level of optimization will vary to suit the final purpose or usage of the 3D model. During optimization, the resulting optimized 3D model is bound to suffer from some level of data loss when compared to the original 3D model acquired directly from laser scanning. This paper discusses a practical method devised by Amber Digital Solutions in maintaining a high level of accuracy of the final optimized model for national archival purposes which requires the highest form of quality.

Keywords: 3D Models, 3D Scanning, 3D Digitization, 3D Optimization, 3D Accuracy

1 Introduction

Every cultural artefact tells a story. Cultural artifacts provide valuable information about how our ancestors lived, the norms they abided by, how communities evolved, their eating habits, rituals, religion and culture and many more. If we were to stich all of the information together, it can help trace our history and enhance our understanding of human civilization. No matter how difficult and costly, it is only in our interest to race against time to help preserve our valuable cultural properties which are now diminishing at an alarming rate due to forces of nature, climate changes, human intervention and damages inflicted by war.

With the advent of 3D scanning technologies, 3D digitization has become the more preferred mode of documenting cultural properties. 3D digitization is a three dimensional digital representation of a physical object in a virtual space. In the process of

Digital Presentation and Preservation of Cultural and Scientific Heritage. Conference Proceedings. Vol. 7, Sofia, Bulgaria: Institute of Mathematics and Informatics – BAS, 2017. ISSN: 1314-4006, eISSN: 2535-0366

digitization, highly accurate 3D data in the form of point clouds are generated which can then be used to construct complex and detailed digital three dimensional models.

Point clouds can be derived from the following methods; Firstly, non-contact (non-destructive) method through optical means such as photogrammetry cameras, structured light or laser scanners and secondly, contact method through the use of probes. Both contact and non-contact methods help capture the shape of physical objects in the computer world. However, each method comes with its own pros and cons depending on the type of scanning technology used - optical scanners using triangulation method are more apt to digitizing minute objects with fine details while optical scanner using the time-of-flight method are more suited to scanning bigger objects of simple geometries. Even among scanners of the same technology, performance varies due to internal R&D effort by the respective manufacturers. For instance, some scanners may respond better to certain materials and some are more restrictive in capturing grooves and edges. However, most optical scanners exhibit a common drawback; that is the failure to effectively digitize highly reflective surfaces, dark surfaces and transparent objects. In such cases, touch probes fit in the loop but in some instances, probes are not permitted such as in the case of digitizing fragile cultural objects.

In digitizing cultural relics and artifacts, due to complex geometries, the presence of multiple materials on a single object, existence of different textures and light emitting surfaces, a combination of methods and technologies have to be used concurrently to capture the shape and details of the objects completely. Multiple scans from several perspectives, including the top and the base, are required to generate a complete 3D model. For large objects, objects with hollow parts, objects with complex geometries, objects with obscured views, more scans are needed. The number of scans can amount to hundreds and even in the thousands. Each scan comprises an accumulation of point clouds whose density varies according to the type of scanners used. The scans would then be aligned and merged under a common reference system to generate a complete 3D model. The 3D model at this stage is the densest in terms of point clouds count. What follows crucially, entails optimizing and texturing the datasets to produce precise sets of 3D models that resemble the physical artefacts in all aspects.

1.1 Objectives of the Paper

This paper attempt to share with readers some real case common errors committed by modelers during the final phase of generating digital 3D models of physical artefacts.

The paper will then present a simple but yet practical method of maintaining accuracy in optimizing digital 3D datasets and generating 3D models of cultural artefacts with minimal data loss.

2 The 3D Model Creation Process

A lot of literature on 3D scanning pipeline for cultural properties has already been presented in many technical journals. The author will not go into too many details. In an overview, the 3D scanning pipeline comprises:

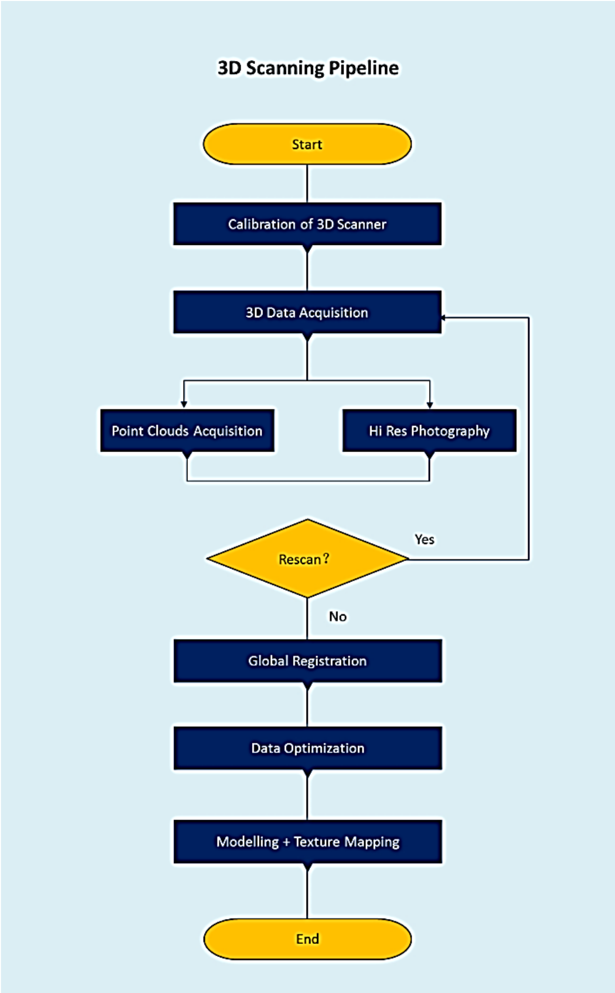

Fig. 1. The 3D Scanning Pipeline

2.1 3D Data Acquisition – 3D Scanning

Depending on the types of material, size and form of the artefacts, multiple types of 3D scanners will be employed concurrently to capture the entire geometry of the artefact. Scanning will be performed from several angles to ensure that no areas are overlooked. Datasets come in the form of very dense point clouds which can be converted to polygons for sculpting and modelling.

Fig. 2. 3D scanning in action

2.2 High Resolution Photography

Here, texture and exact color information of the cultural object will be acquired under controlled lighting conditions. To achieve very crisp details, each high resolution photograph covers only a very small area of focus. The photographs will be cropped and touched up using photo editing softwares.

Fig. 3. High resolution photography in action

2.3 3D Optimization and Modelling

3D scanning of objects will yield very large datasets. When attempting to reconstruct models from laser scan data, large processing power will be required of computers. When datasets get too huge to be processed, it is pertinent to reduce the size of datasets while minimizing the loss of information concurrently.

Fig. 4. 3D model production of an Urn for Hebei Museum

Optimization involves 2 stages. For the first phase, the 3D point cloud model will be checked for registration and alignment, checked for holes and patched by further scanning those areas that have been overlooked, cleaned by removing noise and overlapping point clouds and eventually smoothened it if necessary. For very large objects, point clouds may come from different scanners. To merge these scans arising from several scanners into a complete model, these point clouds will be imported to a third party software to perform global registration. Finally, the point cloud model will be wrapped and converted to polygonal mesh before transferring to the next phase of optimization.

The second phase of optimization involves reducing polygon counts and re-mapping the polygonal model into a NURBS surfaces model. This process may be executed by using off the shelf softwares but may not yield satisfactory results in our cases. Hence, human intervention may be required.

3 Why Acquiring Accurate 3D Models of Cultural Artefacts is Important

Prior to discussing the errors that arise at the final stage of generating 3D models, let us first understand the importance of producing precise 3D models. In the cultural heritage industry, 3D models represent an interesting tool for documentation and interactive visualization, for creating a virtual reality environment or even for recreating destroyed objects. For instance, 3D models obtained by laser scanning can be used to fill a virtual environment with real objects in order to get a wholesome copy of a real environment, such as the interior of a museum or historical building. In other instances, a 3D computer model generated using old images can be used for a physical reconstruction of a destructed statue.

3.1 Documentation, Archival and Research

Documentation of cultural properties involves the gathering and recording of information for purpose of establishing facts or providing evidence of facts or testimony. The main aims of documentation are:

- to record information discovered during excavation, examination and after conservation activities that enhance understanding of the cultural property. These may include information on the measurements, shape, structure, color, texture, material and history of the cultural property;
- to accurately capture the as-found and as-built conditions of the cultural property during excavation and after conservation activities respectively;
- to provide reliable information that assists in restoration and maintenance of the cultural property;
- to record analyses of materials and investigative studies of cultural property that can assists in the understanding of the history and social significant;

Information can come in the form of photographs, text, graphics, audio and video media. With so many types of information co-existing concurrently, what better way is there than to correlate all the information to a 3D model of the cultural property itself. Thus, for efficiency and versatility reasons, a proper and precise 3D model of the cultural property is very essential to present the information accurately to users who may need them.

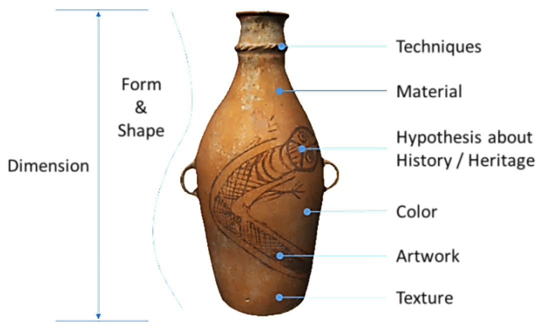

Fig. 5. Types of information available on a 3D model

3.2 Restoration / Reconstruction

Restoration of cultural properties is a very complex process which requires multifaceted expertise from several disciplines such as archaeology, history, visual arts, photography, chemical and material engineering and computer simulation.

1. Reconstruction of Missing Geometry.

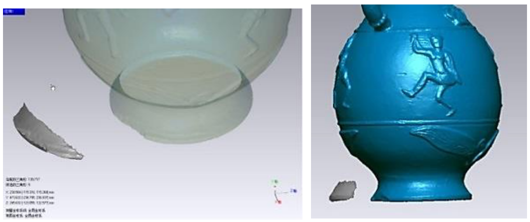

Fig. 6. Restoration of a missing part using 3D data

Cultural properties are not always discovered in its intact form. Even when they are discovered in their original form, some are fragile and may be damaged during transportation and some may just deteriorate over time. 3D data can provide very valuable 3D information for extrapolating and reconstructing missing parts of an exact match. The missing part can first be designed and verified in the 3D space before eventually reconstructed using 3D printing technologies.

2. Color and Texture Hypotheses

An accurate 3D model of the cultural property can assist restorers to propose hypotheses about the original colors of adornments and their texture grains. Restorers can now experiment with colors to derive different hypotheses or even analyses and simulate the grain lines on the body of the cultural object by extrapolation to predict the traditions, techniques and management systems of that time.

Fig. 7. Color and texture hypotheses for a bronze urn cover

3. Substitutes and Replicas

Loans of cultural objects among museums are common practice. When one museum loans out her cultural objects, the museum can replace the original ones with accurate copies without affecting the original theme of its existing exhibition.

Fig. 8. 3D printed copies of a wooden Buddha statue from the National Museum of China

3.3 Authenticity Check

When faced with 2 objects that look almost the same, it is difficult to differentiate the original from the fake with our naked eye. With improved workmanship, consumers can be easily duped into believing that the cultural object is original which in actual fact, is not. However, on the microscopic level, it is not possible to reproduce a duplicate that is identical in form, shape, color, texture and substance. For this reason, a 3D model becomes a valuable assessment tool to verify the authenticity of a cultural object. By inputting both the original 3D model and the newly scanned 3D model of a duplicate onto a 3D space, the characteristics and features of both models can be compared and examined for deviations.

3.4 Digital Reassembly of Cultural Objects

Large cultural objects were often discovered in fragments. Some fragments were discovered in close proximity and some are scattered over the place due to soil movements. Physical reassembly of the fragments had to be performed by several archaeologists manually, a very tedious and time consuming process.

The availability of digital models provides an alternative to assembling the fragments in the 3D space. However, for the digital assembly to be effective and efficient, the 3D models have to be accurate, otherwise the fragments would not fit seamlessly and it would not be possible to derive a complete model of the entire object.

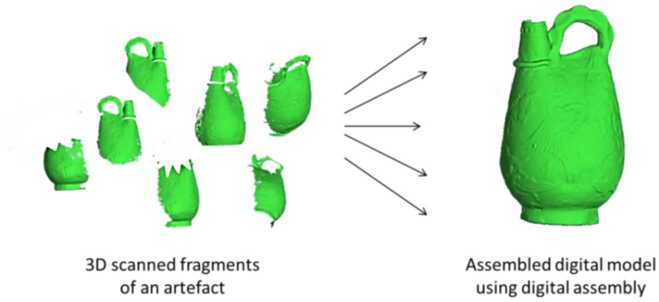

Fig. 9. Virtual reassembly of artefact's fragments

3.5 Cultural Objects' Protective Packaging

A 3D model of the cultural object can be used to design and create precise protective packaging via CNC (Computer Numerical Control) cutting for the physical cultural object. The fitting and enveloping packaging reduces normal stresses by distributing them across the entire surface area of the cultural object.

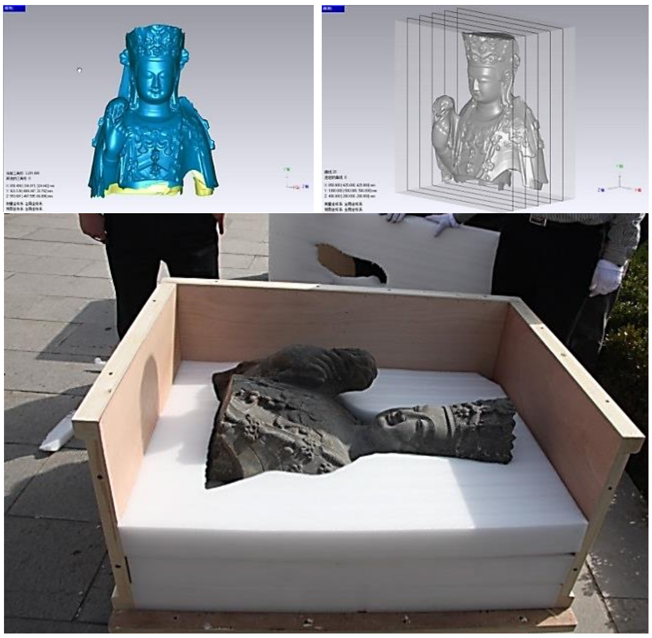

Fig. 10. Using 3D model to design protective packaging for cultural object

4 Errors in Completed 3D Models

4.1 Data Loss – Details

Though 3D data optimization softwares are readily available in the market, they are more applicable to processing industrial parts data where dimensional precision dominates the quality process. In contrast, cultural properties emphasize more on the cultural value derived from the meticulous craftsmanship and artwork of our ancestors, hence, the elaborate and refined designs form the basis of our preservation effort. By applying optimization blindly may result in a huge bulk of valuable information being removed.

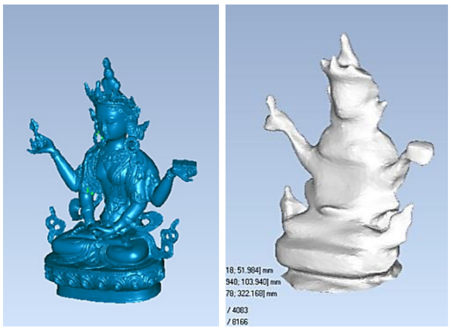

Fig. 11. Example of data loss due to poor optimization.

The example above depicts what happen when optimization is applied irresponsibly to process a 3D model. The resulting facial features, hair contours and adornment characteristics were strikingly absent as compared to the original model acquired via scanning.

In another example of scanning an ultra-huge artefact, the model is optimized to allow processing and running on normal workstations.

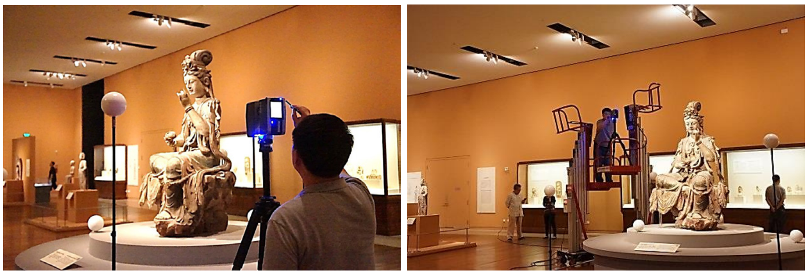

Fig. 12. Digitizing a huge artefact – wooden Buddha statue at the National Museum of China

Upon scrutiny, it was discovered that several intricate details were missing after optimizing the scanned model.

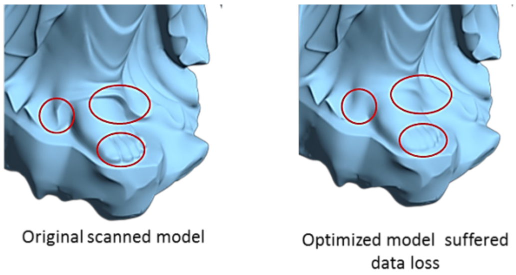

Fig. 13. Data loss during optimization

4.2 Data Loss – Edges

Point clouds at sharp edges being less dense and more scattered are often deemed as noise and removed by optimization softwares. When this happens, the originally sharped looking edge becomes blunted as a result.

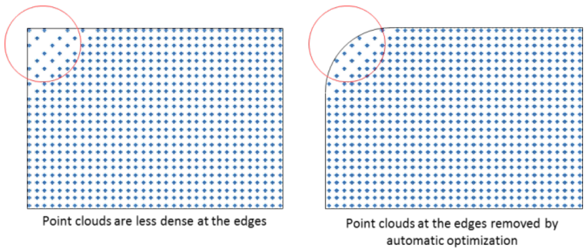

Fig. 14. Point clouds at edges removed during data optimization

In one of our digitization project of an ancient Chinese ink pad and its display box, the edges of the box were "smoothen out" during the automatic optimization process. Edges were restored upon our internal quality check process.

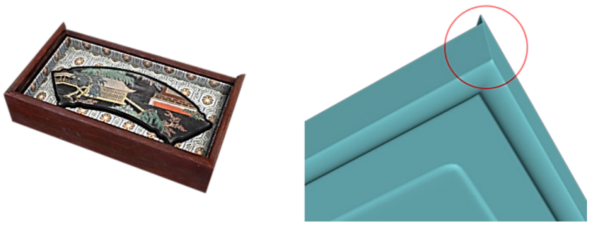

Fig. 15. Original 3D model of artefact depicting sharp edges

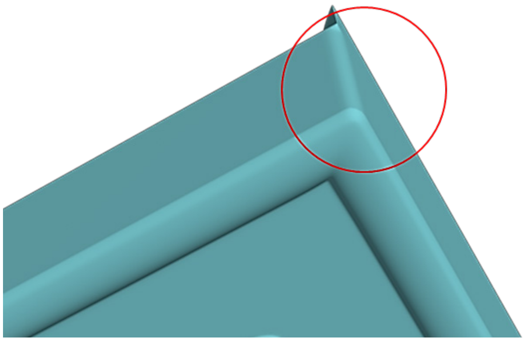

Fig. 16. Edges were blunted during optimization

4.3 Inaccurate Data Addition / Replacement

The addition of data is one error that many people overlooked. During the optimization of very undulating surfaces such as grooves and ridges, these softwares may detect the indentations as “holes”. When this happens, data will be extrapolated to patch up the groove in between the two ridges.

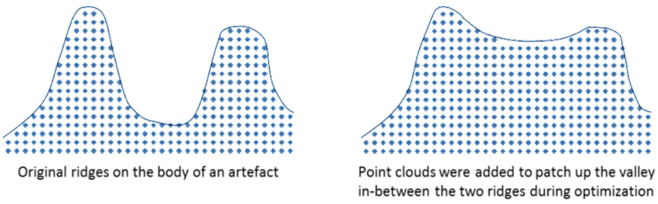

Fig. 17. Illustration of the addition of data during optimization

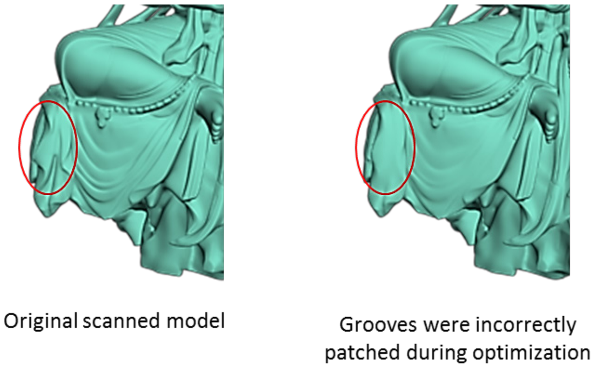

Fig. 18. Example of data addition during optimization

5 Quality Control - Ascertaining the Accuracy and Resolution of Post Rendered 3D Models of Cultural Artifacts

5.1 Conceptualization

With the advent of 3D scanning technologies, 3D modelling has become an important part of manufacturing and assembly of industrial parts. 3D models are now widely used for first article dimensional analysis, failure analysis, design and prototyping, inspection and quality control and reverse engineering. We will investigate how the essence of industrial parts inspection can be applied to the inspection of digital models of cultural artifacts.

A typical industrial part inspection may go like this. A CAD model of the industrial part is first produced. The industrial part is then fabricated using precision machining or 3D printing. The fabricated part is then digitized using 3D scanners to generate a 3D model. By comparing both the CAD model and the 3D scanned model on a common platform, the dimensions of both models can be checked and assessed for quality and tolerance issues.

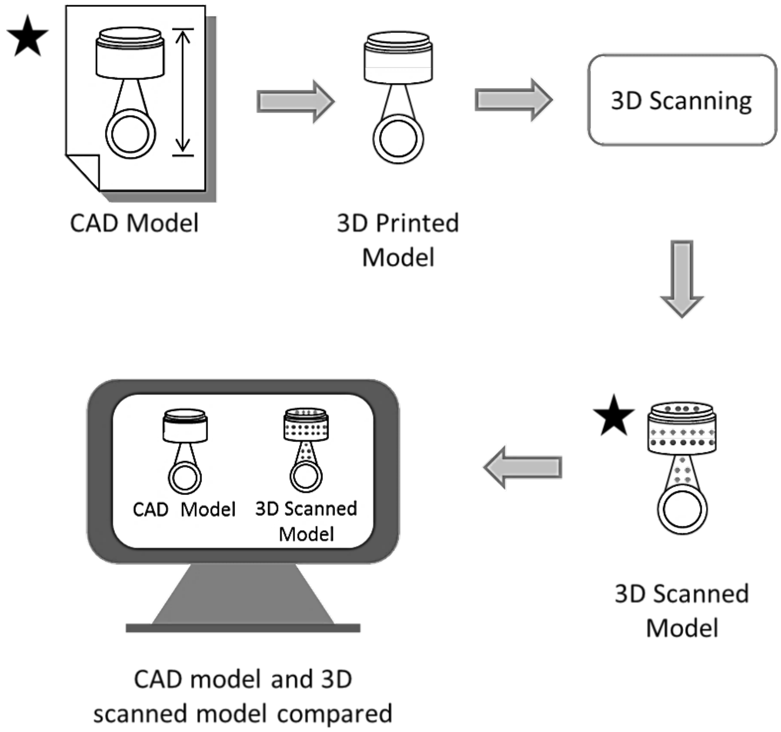

Fig. 19. Inspection of an industrial part using 3D scanned models – Comparing CAD model to 3D scanned model

In our case of cultural objects, the final product is the optimized model. Our objective is to ensure that the optimized model after data adjustment and color texturing is still accurate and precise. Reasons for achieving accuracy have been discussed in Section 3. Accuracy of the optimized model is achieved by checking the optimized model against the scanned model diligently.

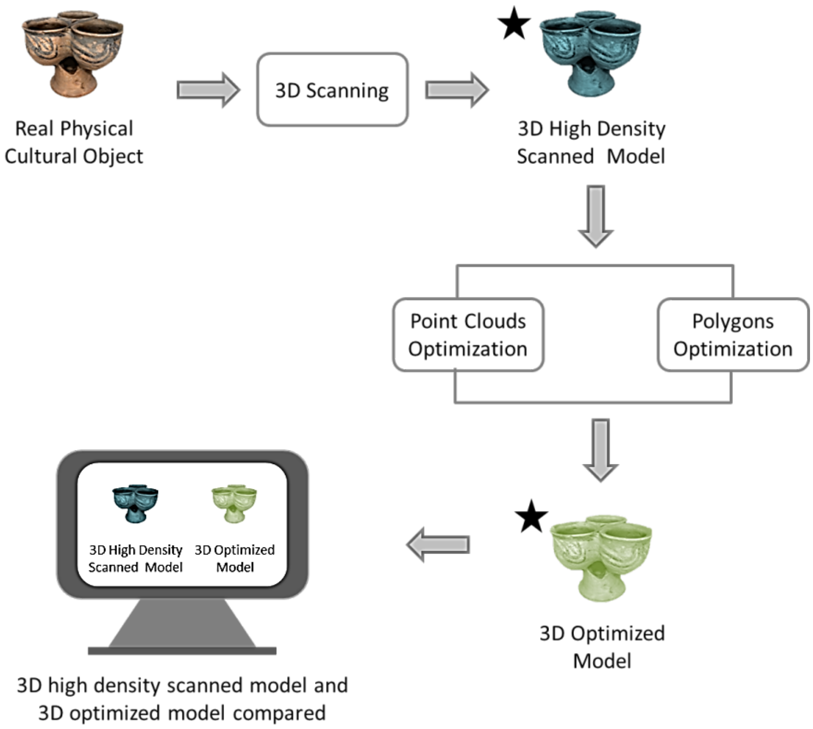

Fig. 20. Comparing optimized model to 3D scanned model

5.2 Implementation

The author named the model accuracy check software as "Amber Form". First, both the scanned model (referred to as the reference model) and the optimized model (referred to as target model) are loaded into the software.

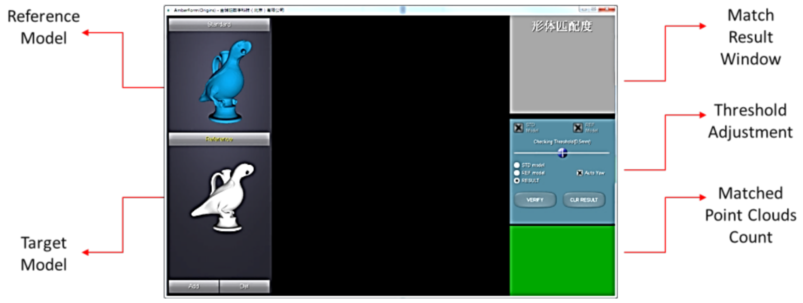

Fig. 21. Inputting reference model and target model

Threshold refers to the distance between the point clouds. The smaller the threshold, the higher the accuracy check. Below diagrams illustrate the results at different threshold levels.

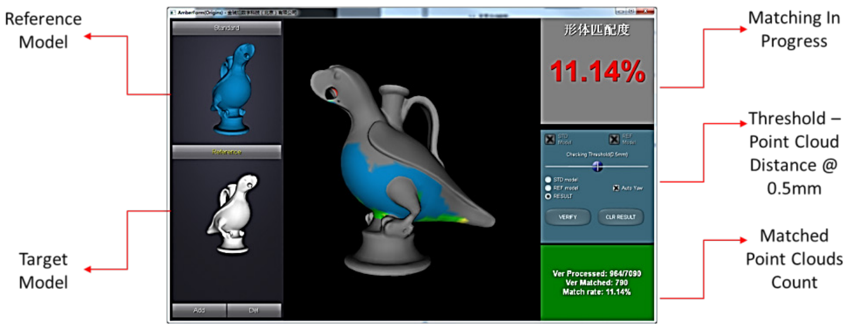

Fig. 22. Snapshot of matching in progress

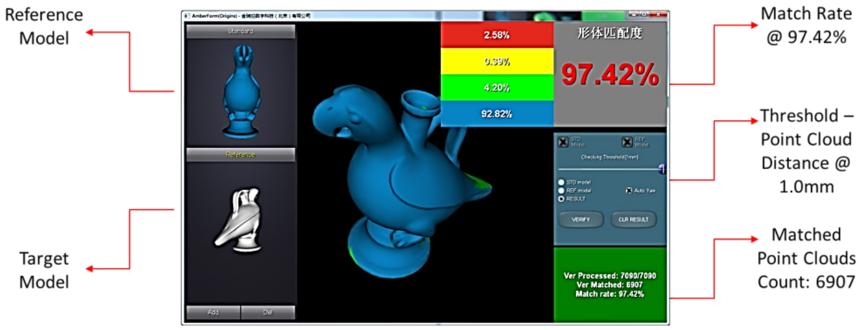

Fig. 23. Matching result of 97.42% at threshold of 1.0mm (Point cloud distance)

In a global 3D space, the software will start to match the point clouds of both models according to the point to point distance set by the threshold value. Point clouds from the optimized model will be compared to the point clouds on the scanned model on a point to point basis. The number of points deviating from the threshold value will be sorted, filtered and calculated to output a final match rate.

Matching results fall into 4 categories which are color-coded as follow:

- Red - Out of match (threshold ≤ deviation)
- Yellow - Good match (1% ≤ deviation from threshold < 3%)
- Green - Very good match (0% < deviation from threshold < 1%)
- Blue - Perfect match (0% deviation from threshold)

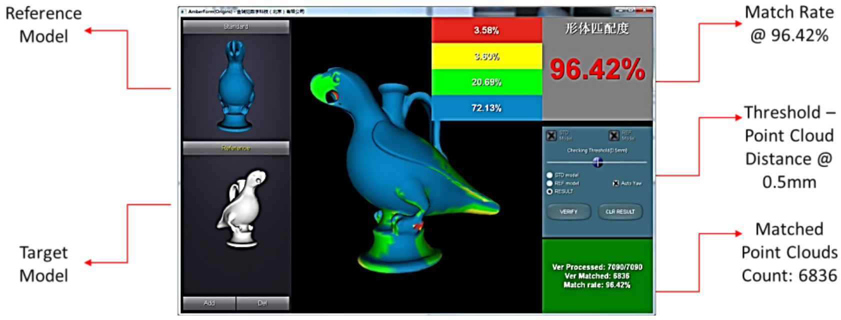

Fig. 24. Matching result of 96.42% at threshold of 0.5mm (Point cloud distance)

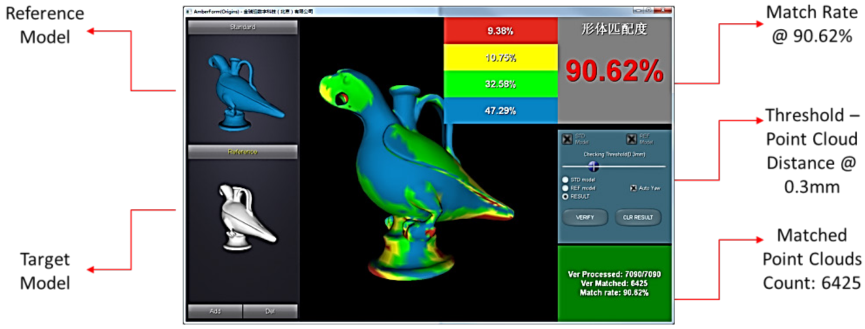

Fig. 25. Matching result of 90.62% at threshold of 0.3mm (Point cloud distance)

Sample results are as follow:

Table 1. Illustrating the matching results according to different threshold values

Test	Threshold Value	(Point Clouds Matched) / (Total Point Clouds Count)	Match Rate
1	1.0mm	6907 / 7090	97.42%
2	0.5mm	6836 / 7090	96.42%
3	0.3mm	6425 / 7090	90.62%

It can be seen that as the threshold value gets smaller, the more stringent the check becomes, and a lower match rate will be derived. The software serves as an inspection tool to ensure that the optimized model is as accurate and precise within an acceptable tolerance.

6 Conclusion

The making and passing down of material cultural properties in the form of artefacts, artworks, buildings and tombs are attempts by our ancestors to pass down their wisdom and experiences to the later generations. They provide us with the basis for in-depth understanding of the political, social and economic situation during the ancient time. Besides enhancing our understanding of preceding generations and their history, learning to appreciate the rich heritage behind the cultural properties helps to inculcate a sense of unity within a communal cluster. The preservation of cultural properties is thus very sacred and significant.

Theft, loot, damage inflicted by war and forces of nature, improper and irresponsible preservation activities among others, are putting cultural properties at constant state of risk. By combining multiple facets of information ranging from form, dimensions, artwork, color and texture onto a common body, 3D technologies inadvertently becomes the preferred mode of preservation.

Albeit 3D digitization technologies becoming more and more effective in preserving cultural properties, the value of the 3D data can only be developed to the maximum if they are acquired to the fullest and finest details. Only when the datasets are precise then can curators make use of the datasets to derive accurate hypotheses, design accurate packaging and of course develop creative contents for purpose of disseminating the history and heritage behind the cultural artefacts.

The author wishes to conclude the report with an ending note - “Preserving cultural properties is our duty, preserving them right and proper is our responsibility!”.

Received: May 16, 2017
Reviewed: June 21, 2017
Final Accepted: June 26, 2017