MEASUREMENT OF TRANSPARENT PLASTIC SCULPTURES USING PHOTOGRAMMETRY, LASER SCANNING AND TOUCH PROBING FOR CONSERVATION PURPOSES

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ABSTRACT:

Tate is currently undertaking a multi-disciplinary research project to document plastic sculptures by Naum Gabo (1890-1977). Gabo experimented with cellulose nitrate and cellulose acetate, materials which interestingly for photogrammetrists constitute early photographic film base materials upon which a significant body of measurement and analysis research is based. Some of these early plastics are now showing typical signs of deterioration even though they are stored in stable environmental conditions. Faced with the gradual loss of a substantial part of an important collection, UCL and PCA were invited to undertake a study of available measurement technologies that could be used to accurately document the sculptures. This paper reports on the advantages and disadvantages found with each technique supported by quantitative comparison data. An image of 'Spiral Theme', one of the sculptures included in the study can be seen in Figure 1.

Figure 1. Spiral Theme

1.   INTRODUCTION

The Tate has a large collection of early sculptures by the constructivist artist Naum Gabo, thanks to donations from the artist and his family. As well as full size sculptures the collection also includes a number of the artist's working models. Gabo's career as a sculptor began around 1915. He was part of an influential group of artists that were experimenting with modern materials in an attempt to produce a new kind of sculpture. His sculptures were constructed from plastic sheet, sometimes in combination with wood, card, glass and metal. He used these new plastics in complex geometric forms which utilised their transparency and flexibility. He continued to create sculpture until his death in 1977

Despite storage in controlled conditions and a constant programme of monitoring, several of Tate's sculptures by Gabo are now showing signs of degradation due to the inherentinstability of these early plastics. Familiar signs of degradation have been observed that include warping, crazing or misting and often cracking or breakage. Currently, conservators are able to slow the onset of this degradation but they are unable to stop it once it has started. The changes that result can be both rapid and destructive. The fact that more of Gabo's plastic sculptures are now changing beyond the point of acceptable display led the Tate to engage in a project aimed to find methods to accurately document their 3D forms before further degradation took place. (Morgan et al 2007)

One component of this study was to undertake accurate geometric measurement of several of the sculptures using both contact (touch probing) and non contact (laser scanning and photogrammetry) measurement techniques. This paper reports on the advantages and disadvantages found with each technique supported by quantitative comparison data. Example images of a sculpture taken from a series of images used for photogrammetric monitoring are given in figure 2 (top). Immediately evident from the imagery is the challenging nature of the semi-transparent subject matter for any form of established optical measurement process, particularly when it is considered that conventional targets cannot be adhered to the surface of the sculptures and that the early plastic remains transparent in most areas. Where the plastic is degraded it may appear either discoloured or even opaque presenting the conservator with a major problem, but the measurement technology with a better opportunity of recording the surface.

The project team agreed that a combined method based on photogrammetry, laser scanning and touch probe sensing should be investigated to accurately document the dimensions of the sculptures in 3D.

2. DIGITAL PHOTOGRAMMETRY

Photographic recording is an established methodology for the documentation of art work providing a key tool in conservation. With the advent of very high resolution digital camera technologies, such as the Hasselblad H2D and H3D 39MP imaging systems (7216 x 5412 6.8µm square pixels), digital imaging is becoming accepted as an appropriate alternative to traditional film base photography in almost all areas of photographic practice. Given the well understood geometrical and optical stability of such digital cameras it is logical and relatively straight forward to incorporate established coded target, bundle adjustment and camera calibration procedures within an image capturing process that is designed to image each sculpture from a systematic range of viewpoints.

Since reliable calibration of the camera was difficult using such a sparse point data set, a rigid 3D calibration array of coded and retro reflective targets occupying a similar volume to the sculpture was constructed to pre-calibrate the camera. A calibration was obtained with a set of highly convergent images including a subset rolled about the optical axis of the camera were processed within a bundle adjustment strategy (Granshaw, 1980).
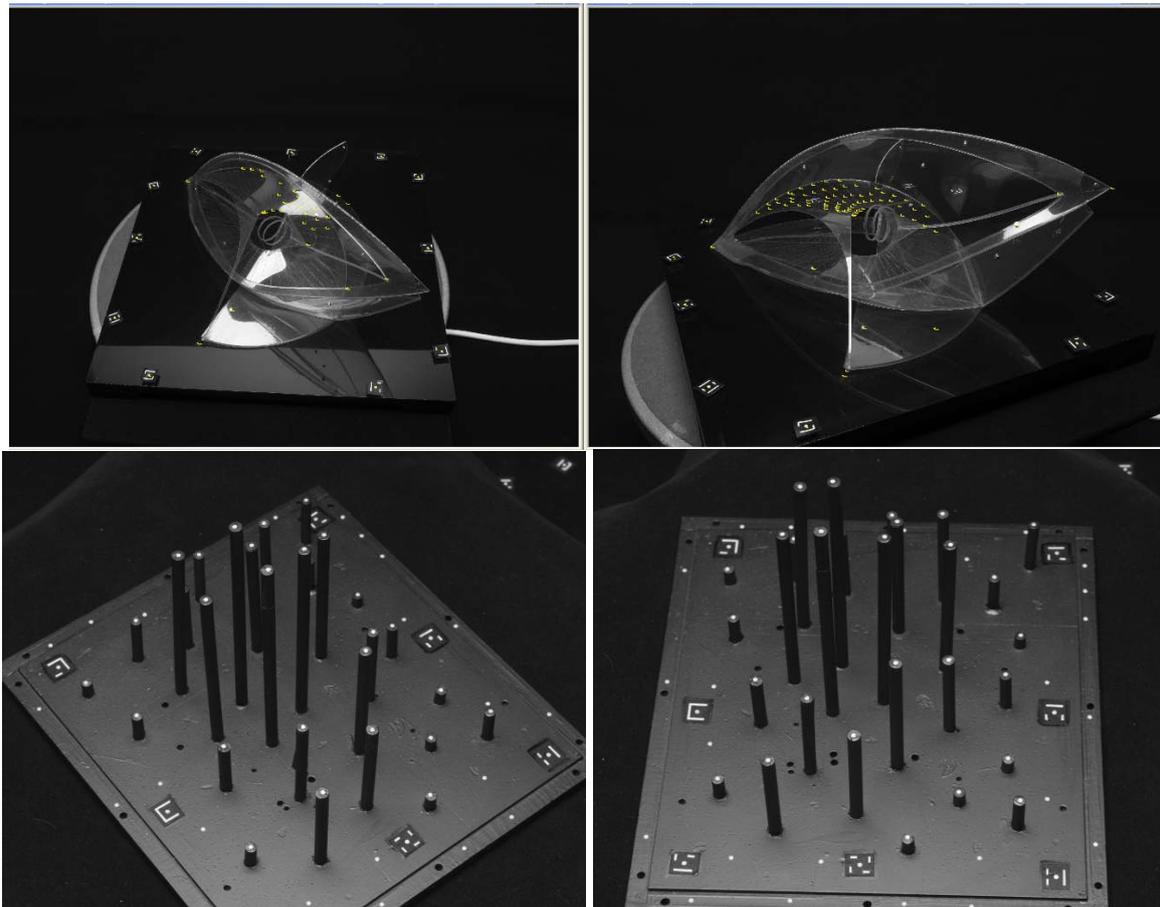

Figure 2: Example images from a photogrammetric survey of 'Spiral Theme' (top) and calibration object (bottom).
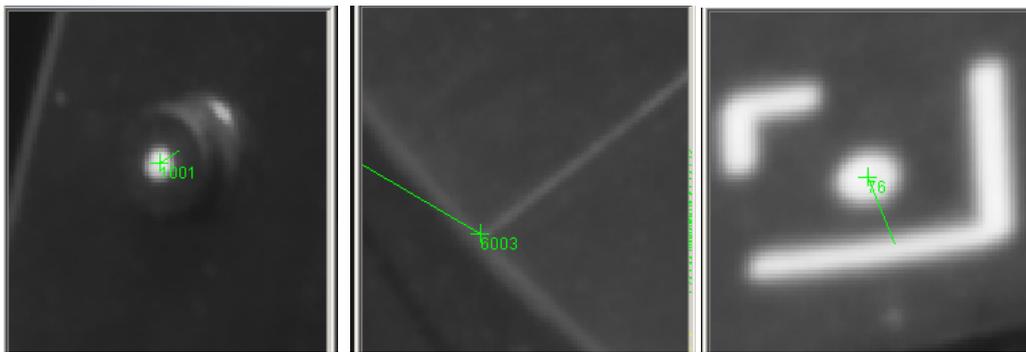
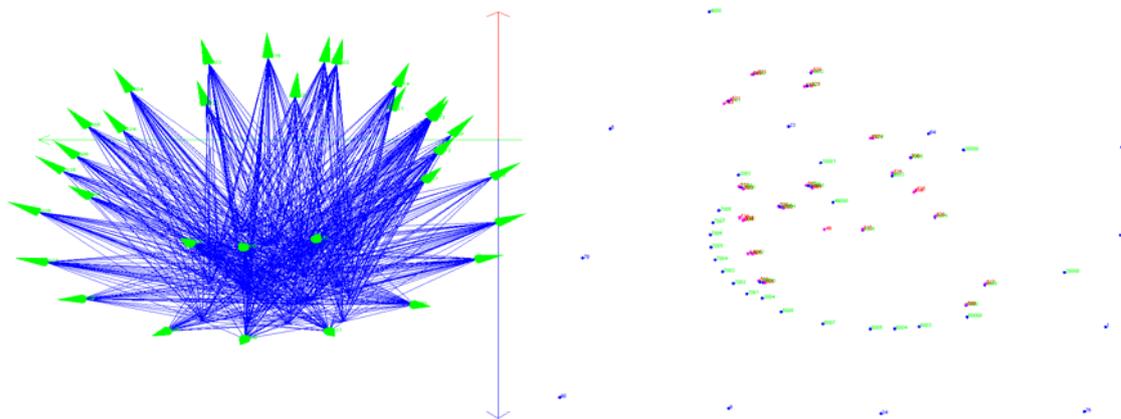Figure 3: Examples of key features identified from multiple images using multi-epipolar image constraints.

Figure 4: Schematics demonstrating the network geometry and coordinated key features identified using multi-image epipolar constraints. Images were captured a single camera and rotation of the sculpture on a turntable (VMS software).

Exposures	32
Network Targets	54
Observations	1571
Unknowns	364
Unit Weight Estimate (a posteriori s0)	1.00
RMS Image Residual	2.29 μm
Mean Object Space precision	15.81 μm
Relative Precision	1:40,000

Table 5: Photogrammetric survey statistics following an external constraints self calibrating bundle adjustment
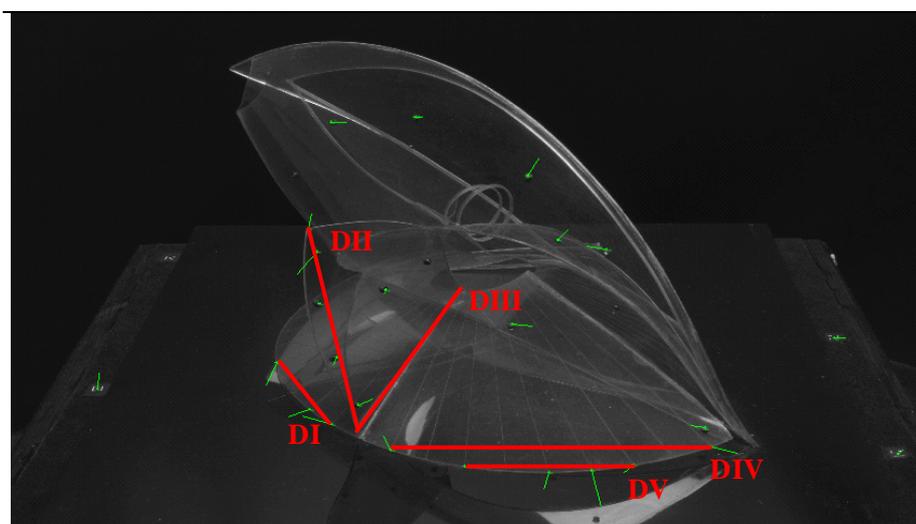

Figure 6: Overlay of independent check measurements used to validate photogrammetric dimensions

In order to define an appropriate coordinate system for sculpture recording a rigid datum was identified by digitizing (touch probing) the coded targets surrounding the sculpture. These coded targets were subsequently treated as control within an external constrains datum adjustment. 3D measurements of the sculpture were computed based upon this coordinate system defined by the located control targets and using any identifiable detail points on the sculpture surfaces (tie points) (Figure 3). Such detail points include markings made by the artist, edges, corners and any local surface detail. A lack of sufficient natural features necessary to ensure reliable coordination throughout the volume of the sculpture led to the introduction of small neodymium magnet targets around 3mm wide. These magnets, providing a white target dot on a black background, could be introduced on either side of the plastic without affecting the surface (Figure 3 left).

Figure 4 demonstrates a typical photogrammetric network used to record each sculpture. In each case the sculpture was mounted on a turntable to incrementally deliver the very high degree of overlap necessary to overcome occlusions and to provide a photogrammetric image capture method which could be repeated and if necessary automated to measure the wide range of sculptures in the Tate collection.

Table 5 provides summary statistics from a photogrammetric network adjustment in which both retro-targeted control points and natural features have been included. The bundle adjustment resulted in a mean target precision at the order of 16μm (object space). Considering the demonstrated relative precision (1:40,000) the achieved measurements are highly optimal given the relatively low quality of the artificial targets (magnets) and the supportive natural features. Much of this is due to the excellent imaging capabilities of the Hasselblad H3D camera.

In order to independently check the photogrammetric data, a series of inter-feature distances were defined and measured on the sculpture with calipers by a conservator. Figure 5 gives an example of a set of comparative point data coordinated within the photogrammetric network. Since image matching was not possible due to the highly specular and transparent nature of the plastic surfaces identtifiable points on the surface and image edges were extracted interactively supported by a correspondence solution based on multiple epipolar line

intersection. Table 7 presents the differences between each of the measurement methods where discrepancies of up to 0.8mm were observed. Whilst the photogrammetric network has estimated the precision of the 3D point coordinates to at least an order of magnitude better than the observed discrepancies, these data demonstrate the difficulty in physically measuring surface points without contacting the sculpture.

Distance	Caliper	Photogrammetry	Discrepancy
DI	67.420	67.232	0.188
DII	90.580	91.149	-0.569
DIII	98.720	99.534	-0.814
DIV	130.890	130.751	0.139
DV	67.650	67.665	-0.015

Table 7: Check Measurements (mm).

3. TOUCH PROBE SENSING

Touch probing is an established practice in engineering measurement with the CMM mounted probe providing the mainstay for dimensional metrology of small manufactured objects. In this case a CIMCORE Infinite Arm system was used with a touch probe digitising directly into RhinoCAD software. The established practice of using a measurement arm equipped with a probe provides a flexible method of on-site measurement. This method was included in the project to provide a fall back approach that whilst labour intensive and time consuming in the studio was guaranteed to deliver data. A key issue to the quality of this data is the necessity to touch the surfaces which being particularly thin and flexible are likely to deform during the touch process. This is offset by the advantage of being able to capture the key edge boundary information necessary to directly generate a 3D model assuming smooth continuous connecting surfaces.

Comparison between the photogrammetric data and points measured with the touch probe (Figure 8) were found to agree within 0.3mm for clearly identifiable photogrammetric control targets. The discrepancy increases to 0.8mm for key features on the sculpture; something that is unsurprising given both the difficulty of identifying common locations when making measurements and the stability of the sculpture during touch probing.
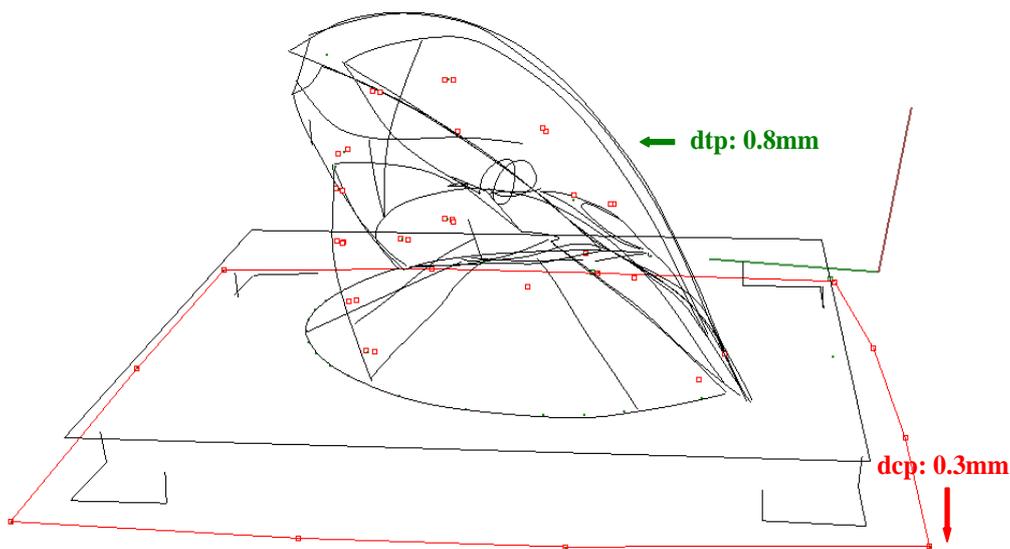

Figure 8: Images created in RhinoCad from touch probe data with overlay of photogrammetrically computed points
(dcp: discrepancy to control points, dtp: discrepancy to photogrammetric tie points)

4. LASER SCANNING

Technology for the close range scanning of small objects has undergone significant developments in recent years with a wealth of triangulation systems being available in both static and mobile configurations. In this case a key requirement was that the sculptures had to remain within the sculpture conservation facility at Tate. An arm based scanning system (Cimcore Infinite arm and ScanWorks V4 head) was available. This system had the advantage that it could be easily transported to site, had a reach that was appropriate for all of the sculptural material under investigation without needing to move the scanner base and could also be interchangeably equipped with a touch probe.

In common with photogrammetry, the transparent nature of the sculptures and their highly reflective surface meant that this instrument would be reliant on receiving laser reflections from the surface that (a) did not saturate its sensing system when the surface normal was such that the laser light was reflected directly at the sensor and (b) provided a strong enough return when the surface orientation directed the majority of the light away from the sensor. Transparency was also an issue as the laser illumination could be reflected from the upper and lower surfaces of individual plastic layers in the sculpture. The detailed view in Figure 9, demonstrates regions where the surface could not be detected (black voids) and laser reflections from upper and lower surfaces due to varying incidence angle of the laser illumination. It is also possible to identify transitions in scanner recording between the upper and lower plastic surfaces.

Although the sculpture was fixed within the data acquisition process the software tools used to communicate with the laser scanner and the touch probe (Innovmetric Polyworks Ver. 10 and Rhinoceros CAD Ver. 4 respectively) required a subsequent registration due to the variant local datum within both systems. Whilst a black-box to the end user software tools perform a point or polygon phase registration procedure based on the standard ICP strategy (Besl and Mc Kay, 1992).

These techniques provide a standard method for matching dense surface sets together, but were thought to be inappropriate for the purpose of matching a very sparse point set to a very dense one. To give an indication of ICP capability several registrations were carried out employing a range of initial alignments between models and subsets sparse target points in Geomagic Studio 7. Table 11 presents the registration output from the point-based registration procedure followed here. The registration was processed with an initial pre-alignment from a sparse set of control points which was iteratively refined against the complete sparse photogrammetric point cloud. It is evident that whilst the general agreement is at a level of 1mm localized discrepancies are evident in the data due to ambiguities in matching very sparse against highly dense points-sets. To avoid this process it would have been better to use geometric targets the centre of which could be resolved through surface fitting.

ICP input control data	Statistics
Control Points- (Base-Plane)	Average dist: 1.02 mm Stdev: 1.24 mm
Control Points- (Base-Plane& Sculpture)	Average dist: 1.08 mm Stdev: 1.29 mm

Table 11: Sparse to dense cloud registration statistics
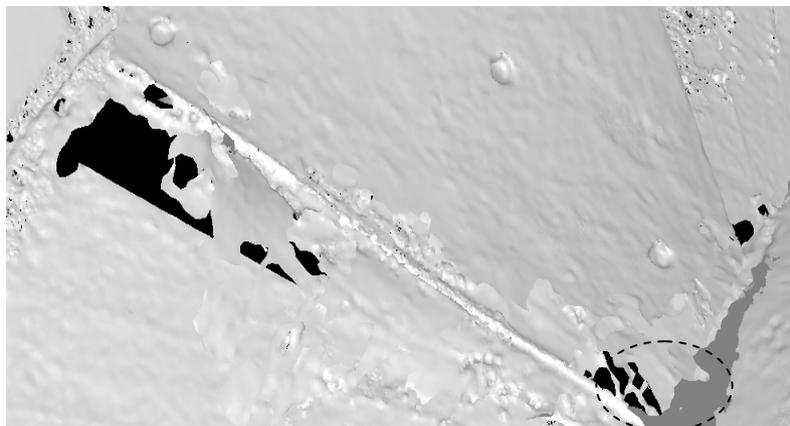

Figure 9: Local detail demonstrating the data attainable from Spiral Theme sculpture after triangulation (Pointstream software)
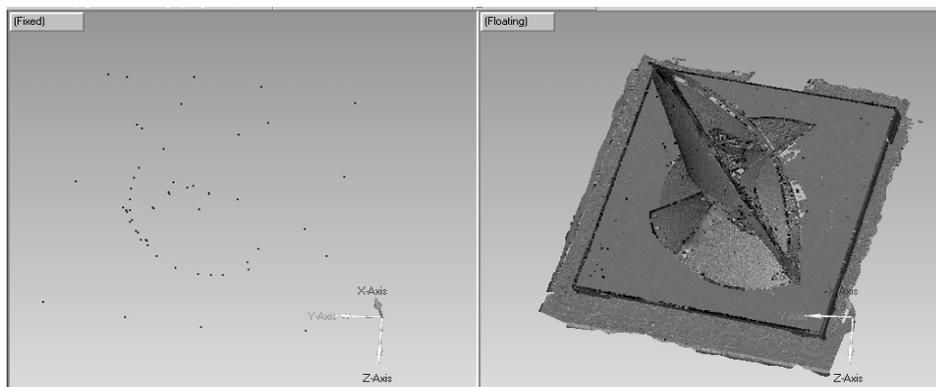

Figure 10: Sparse data from point based photogrammetry registered to laser scan data after triangulation (Geomagic Studio)
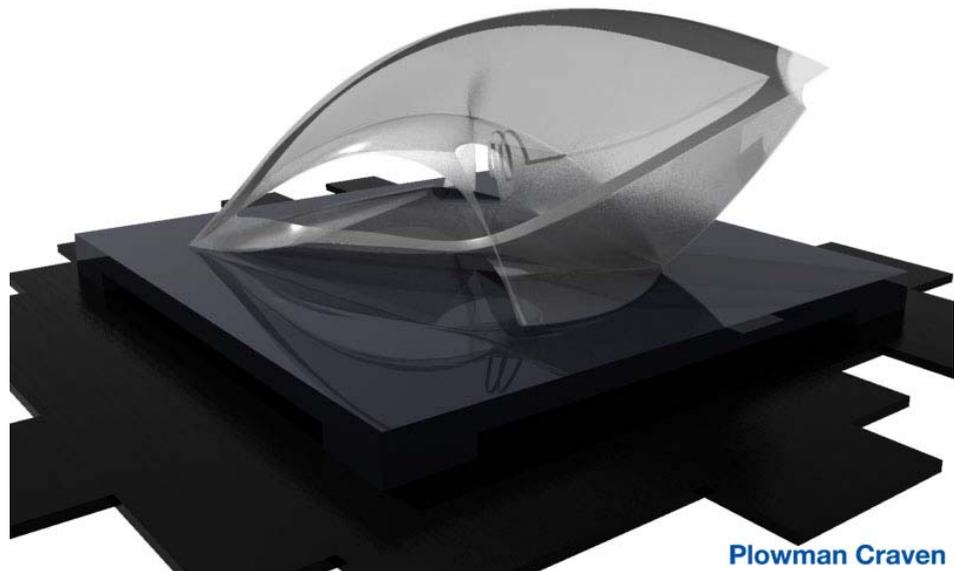
Figure 11: Virtual reconstruction of 'Spiral Theme'

5. VIRTUAL RECONSTRUCTION

To further consider the value of these techniques for documentation and reconstruction, virtual models of both sculptures were engineered by Plowman Craven. This work utilised the spatial framework provided by the probe data in combination with the other data records to generate an "as measured" computer model of each of the sculptures. A virtual reconstruction of Spiral Theme resulting from this process is given in figure 11.

6. SUMMARY

Recording these sculptures has not been an easy task as there is no single technique which can accurately record all of the necessary detail. Whilst each of the three techniques had their strengths and weaknesses when applied to these transparent plastic sculptures it seems that combining them has been very successful to a millimetric level of agreement.
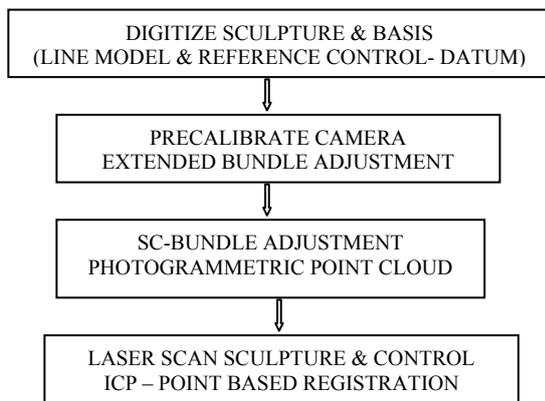

Figure 12: Method for the documentation of the sculptures.

The information gained by the conservators has vastly mproved documentation of the two sculptures recorded as part of this pilot study. This successful work has permitted a second phase to document four further sculptures using the same ethodology (figure 12).

The ability to capture such detailed 3D data has given the conservator a number of options and possibilities for the future. As well as providing a quantitative periodic recording capability of any geometric changes (Robson at al 1995) there is a realisation that the 3D model obtained is from a sculpture that is already warped and damaged Tate is currently exploring ways in which this 3D information can be used to present the artwork in a manner that is closer to the artist's intent.

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