

MICHELANGELO'S DAVID: HISTORICAL IMAGES FOR THE PRESERVATION OF A MASTERPIECE

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KEY WORDS : calibration, close range, photogrammetry, preservation, sculpture

ABSTRACT

On the occasion of the restoration and the studies carried out for the 500th anniversary of the completion of Michelangelo's *David*, the *Laboratorio di Topografia* of the University of Perugia has contributed to the research conducted on determining the position in which the statue stood in the period during which historical sources reported the forming of cracks in some parts of the sculpture. In particular the study intends to identify the deviation from the vertical position, i.e. from the position that Michelangelo had conceived and given it when creating the work. The change from the original position probably caused the cracks observed, and thus it is clear how important it is to determine the degree of inclination for the future preservation of the work, considering above all dynamic actions such as earthquakes or vibrations to which the statue may be subjected. An accurate analysis of photographic records made it possible to recover images made by the photographer and sculptor Anton Hautmann in the years 1858-1862 showing the *David* in its original location in Piazza della Signoria. The narrow photo base with respect to the camera-object distance prevented the use of traditional photogrammetric techniques based on stereoscopy, favoring instead unconventional procedures. Hautmann's images were calibrated beforehand in order to estimate the interior orientation parameters, and were then used simultaneously to construct a photogrammetric model for deducing the three-dimensional coordinates of any point common to several images. The position and thus the hypothesized inclination of the *David* was then estimated by comparing the coordinates of two sets of homologous points obtained from the aforesaid photogrammetric model and from a survey measurement of the statue done at the Galleria dell'Accademia. This latter survey confirmed the sculpture's current vertical position and furnished a useful base of comparison for establishing the position of the *David* in the mid-19th century.

1. HISTORICAL DOCUMENTATION AND PROBLEMS

Michelangelo's *David* is a symbol of the city of Florence, and thus has been subject to many acts of vandalism which, together with exposure to the elements, have caused it to suffer from progressive deterioration. Consequently, in the mid-1800s various commissions were formed to evaluate the statue's condition. In 1852 the first commission's analysis of the *David* revealed and established that there were in fact some cracks and fissures, particularly in the tree trunk and in David's right ankle. The second commission (1866-1869) not only confirmed the existence of these cracks, but also found that they had considerably worsened, such as to believe "...that even if placed entirely under cover, the statue of the *David* will always need to be supported in some way...". In 1871 the engineer Del Sarto defined the statue's situation more precisely: "...the opinion immediately given regarding the stability of this colossus, apart from the quality of the marble ...is that said colossus is no longer plumb line in which the artist placed it, being tilted ever so slightly in the front part ...". In 1872, the last of the three commissions stated "...briefly the plan of the operations to be performed for fully carrying out ..." its move to another location. Among the procedures listed was the building of a wooden "castle" around the lower part of the statue, the laying of rails for moving it and constant attention to ensure that during transport the statue would maintain "...in every sense its verticality"

Immediately after it was moved in 1873, the discussions and conflicting opinions continued as to the restoration work for strengthening it. There is no documentation, however, on this restoration work and it was probably never done. The *David* was however set on a new base, attempting to maintain the statue's position "...a little bit farther back, without in the least taking away from its effect" (1874).

In following with the problems reported by historical documents, the *Dipartimento di Ingegneria Civile e Ambientale*

of the University of Perugia focused on the sculpture's present conditions of stability. Analyzing the cracks and the mechanical properties of the marble, it was possible to reconstruct several hypotheses regarding the direction and the extent of inclination from 1° to 3° (Borri, Grazini, Marchetti, 2004).

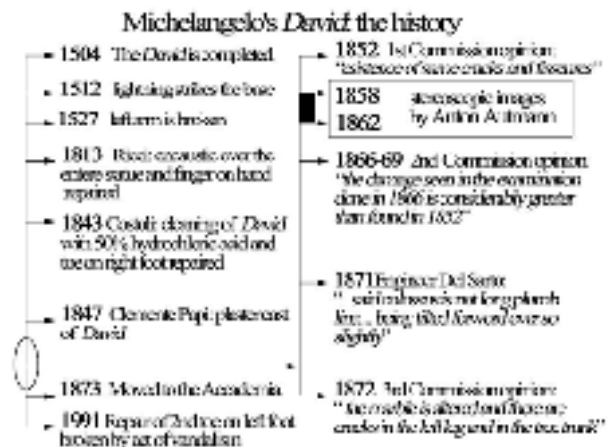
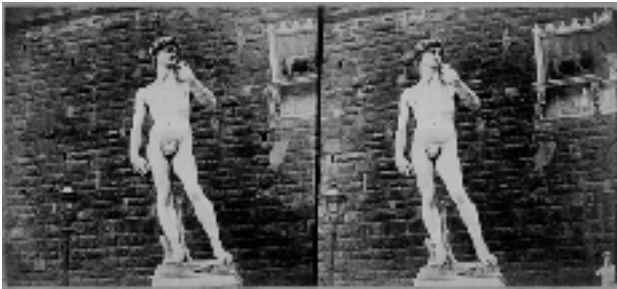


Figure 1. Summary of the most important historical information

Photogrammetry then made it possible to obtain a measurable model, using archival photographs from the years 1858-1862. The reconstruction of a photogrammetric model linked to the past made it possible to make the appropriate measurements, identifying the differences in its vertical position between its current position and the one it had in the mid-19th century. In these terms it was possible to verify and quantify the changes in the colossus's position, restricting the field of the hypotheses formulated solely in relation to analysis of the damage.

2. ANTON HAUTMANN AND HIS PHOTOGRAPHY

About thirty years after Joseph Nicephore Niepce made the first photograph in 1826, Anton Hautmann, already a well-known sculptor, opened a photography studio in Florence. By 1861 his studio was probably one of the most important in town, even though the Alinari brothers, Metzger and Bernoud, were working in the same period. Hautmann's stereopairs date from 1858 to 1862. They are all made from wet glass plate negatives and are printed on albumin paper mounted on paperboard of various colors in the standard format of 72/81x152/164 millimeters. Hautmann's photographic archives include a considerable number of stereoscopic images (173) of various subjects.



Pair no. 1



Pair no. 2



Pair no. 3



Pair no. 4



Pair no. 5

Figure 2. Stereopairs analyzed (Archivio Giorgio Hautmann)

Among these are landscape views of Florence, particular views of the bridges over the Arno, and the first photos showing life and movement in the streets and squares taken from unusual perspectives. The streets in particular are photographed from a decidedly high angle, so as to capture better the spatiality and the relationship with people in movement, often using very long exposure times. Anton Hautmann used different types of objective lenses. It can be supposed that for most of his stereoscopic photographs he used a camera with a single objective lens that could be moved laterally along a track and another camera with two objective lenses. In order to establish whether he used this or that camera, the images were analyzed in regard to the size and the details of the frames. It can be assumed that the single objective lens camera was used when: the frames are of like size and the moment the picture was taken is different, such that the people are in different positions. On the contrary, with the dual objective lenses camera, the frames have a different width and the same moment is imprinted on the plate. He used stereoscopic camera stations with very narrow photo bases, so as to allow a three-dimensional view of the object photographed, but not suitable for a metrical use of the individual pairs, called pseudostereoscopic because of the reduced angles of convergence of the corresponding projective rays. Anton Hautmann's art training is a significant factor in comprehending the formal and technical quality of his photography and, in particular, his sensitivity as a sculptor is evident when he is portraying statues, such as Michelangelo's *David*. Indeed, he takes many shots of the subject from different angles, so as to describe all of the statue's characteristics, attempting to convey its plasticity and leaving to posterity a wealth of photographs that have made it possible to reconstruct a fairly good, virtual, three-dimensional model of the sculpture.

3. CALIBRATION OF NON-METRICAL IMAGES

The main problems connected with the use of photogrammetric techniques for processing images for metrical purposes derive from the geometry of the camera stations used and from the estimating a posteriori of the optical parameters of the camera used. The latter are determined by means of calibration procedures based essentially on the alignment of the objective center, the image point and the object point (*Figure 3*) expressed by geometric relationships defined by the well-known *collinearity* equations. The Direct Linear Transformation (DLT) equations are a faster method compared to collinearity equations, because they directly transform the coordinates from the comparator into object reference system coordinates, eliminating the passage to plate coordinates. With these equations one does not obtain definitive solutions for a good reconstruction of the geometry of the camera stations, but they can be used to calculate the initial values to be entered in the least squares adjustment.

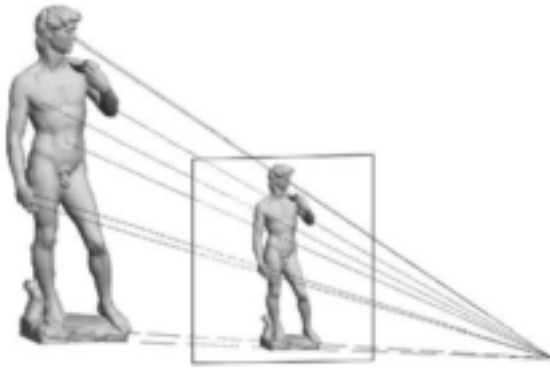


Figure 3. Alignment of the object point, image point and objective center

Nonetheless, the theoretic scheme of perfect central perspective is not respected no matter what mathematical model is used, because of the shifting of the position of the image points due to the radial and tangential distortion of the lens, the nonplanarity of the sensitive material, the deformation deriving from the development and printing stages, and measurement errors. Thus the equations mentioned include the parameters that model the systematic errors generated by the lens, while all other deformations are considered negligible. In order to minimize the errors in the first orientation stage one must know the coordinates of many ground control points which must be distributed uniformly in the area surrounding the object to be surveyed. In this specific case, moreover, there are considerable problems with the identification, deriving from the difficulty of recognizing, in photographs taken one hundred and fifty years ago, reference points which have remained unchanged up till now and which can be measured in an unambiguous manner using traditional measurement instruments.

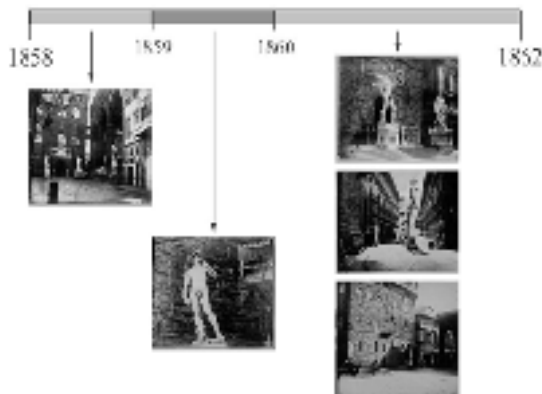


Figure 4. A. Hautmann's stereopairs

In consideration of the uncertainties of the photographic information regarding their use for metrical purposes, the additional problems to be faced can be summarized as follows:

- stereoscopic base too narrow to allow the use of classic photogrammetric methods;
- lack of any information on the specifications of the cameras used;
- optical distortion difficult to model with traditional land photogrammetry algorithms;
- contact print on albumin paper which prevents the univocal identification of the points during video enlargement and makes some parts of the images not very legible, even though the digitalization of the original photographs was done using a high-quality, 3000 dpi Vexcel Ultrascan 5000TM photogrammetric scanner;

- the lengthy time period (four years) over which the photographs were taken is cause for further uncertainty in the overall model: it is implicitly assumed that in these years the statue had not undergone changes in its position, or the determination leads to the estimating of a mean position for that period (Figure 4);
- the last photos available are from 1862 and the statue was moved in 1873. It must be believed that in those years the problems of static origin continued to have an effect until the cracks still present were acquired.

The coordinates of the 240 ground control points used in the subsequent stages (mean accuracy of 1.5 ± 2 cm – the xy reference plane was assumed to be parallel to the façade of Palazzo Vecchio) derive from classic survey measurements by direct resection of points distributed throughout the space surrounding the statue: along the Loggia dei Lanzi, along the buildings facing Piazza degli Uffizi and above all on the façade of Palazzo Vecchio (Figure 5). The latter play a fundamental role in the construction of the model, as they are placed near the Michelangelo's statue of the *David*.



Figure 5. Topographical survey in Piazza della Signoria.

In the mid-1800s cameras were of course hand-built, and therefore no information is available regarding the instruments used by Anton Hautmann: therefore it was necessary to calibrate every single frame. The "Photomodeler" Vers. 5.0 software by Eos System Inc. was used in this stage and in the subsequent construction of the photogrammetric model. The accuracy of this software in the reconstruction of orientation parameters of photographs made by metrical, semimetrical and amateur cameras, using only the knowledge of the ground control point coordinates, was tested in a specific study in the *Laboratorio di Topografia* of the University of Perugia (M. Marrucci, 2005). Each image was then calibrated, entering the dimensions of each frame and the ground control point coordinates taken from the topographic survey as the only initial data.

Stereo pair	Image (pixel)		G.C.P.	F. length (mm)
	Width	Height		
1 left	9574	8515	31	167
1 right	9116	8481	35	158
2 left	10340	8936	49	157
2 right	9422	8936	44	165
3 left	8870	8504	37	133
3 right	8873	8509	26	131
4 left	9144	7699	53	142
4 right	9058	7656	46	143
5 left	9205	8613	63	139
5 right	9021	8590	75	142

Table 1. Results of the calibration of A. Hautmann's photographs

The calibration procedure carried out on each frame provides the interior orientation (principal point coordinates and focal

length) and exterior orientation (camera station coordinates and camera angle values) parameters.

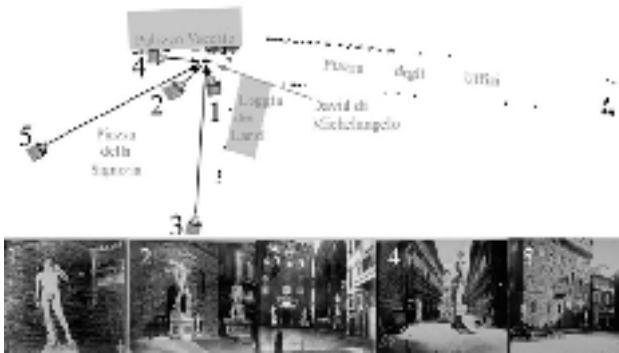


Figure 6. Position of the camera stations, established in the calibration process. The ground control points are shown in black.

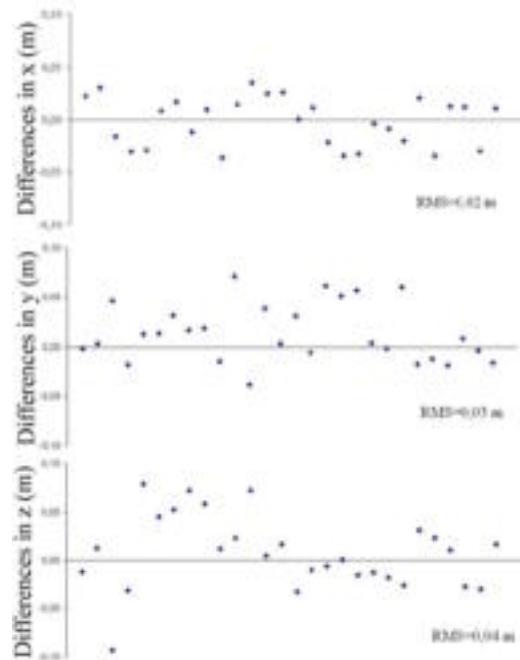
The data obtained confirm that the photo bases of the individual pairs are very narrow compared to the camera-object distance and, therefore, not suitable for the use of traditional photogrammetric techniques. Thus to construct a three-dimensional model it is necessary to adopt unconventional methods that allow the contemporaneous use of all the frames with projective ray convergence angles up to 80°, taking into account also the problem of the different scales of the frames used. The values found for the focal length are of help in the analysis of the various cameras used by Hautmann. With the first two pairs, there are no details that help to establish the time elapsed between one frame and the next, and thus to evaluate with any certainty the type of camera used. In both cases the width between the frames changes considerably compared to the rest of the other pairs; in fact, the focal value varies (pair 1: difference of 9 mm; pair 2: 8 mm). These differences in the focal values are compatible with the use of two separate cameras. In the pair 3 photographs one can clearly see the difference in time; in one frame there is a moving carriage that is missing in the second frame. The particularity of these photos lies in their long exposure times, which show objects in movement, such as the carriage. All in all, the similar size of the frames, the different time periods and the difference of just 2 mm in the estimated focal lengths allow one to suppose that a camera with a sliding lens was used. In pair 4 as in pair 5, the minimal difference in size and in the estimated focal length, as well as details such as objects and persons in different positions, suggest the use of a camera with a sliding objective lens.

4. PHOTGRAMMETRIC MODEL AND THE SURVEY OF THE STATUE IN THE GALLERIA DELL'ACCADEMIA

The photogrammetric model was initially constructed with all ten of the available images using the ground control points and introducing into a single project the calibration parameters of each frame obtained in the previous stage. Subsequently, it was deemed unnecessary to include both images of the pair for an unconventional photogrammetry project, considering it to be not influential for the purposes of determining the overall model. Indeed, the points collimated on the same pair are estimated with great uncertainties, as they have decidedly small angles between the projective rays. 42 ground control points common to at least two frames of different pairs were collimated. 14 of these were set so that the coordinates would not be changed

during the adjustment. The choice of the fixed points was based first on the criterion of distribution homogeneity, and second on their arrangement around the statue. The points near the statue have wider angles between the projective rays, making them generally more reliable. The differences between the coordinates obtained from survey measurements and those obtained with the model for 28 the check points show an RMS of 2 cm along the x axis, 3 cm along the y axis and 4 cm along the z axis, as shown in the following graphs (the reference system used is described in the preceding paragraph). Further analysis of the differences obtained at the check points demonstrates that the accuracy of the model increases with the increase in the angle between the projective rays. The position of the *David* in the 1858-1862 period with respect to its present-day position was estimated by comparing the coordinates of homologous points obtained from the photogrammetric survey with those measured directly on the original sculpture in the Galleria dell'Accademia (the statue now in front of Palazzo Vecchio is a copy). Considering that the angles between the projective rays formed by the check points average 31°, and are thus less than the angles between the projective rays of the points collimated on the statue (average 65°), it can be presumed that the accuracy of the latter points is not less than that of the control points.

Differences in X, Y, Z between the coordinates obtained from survey measurements and the corresponding coordinates obtained from the check points model



$$RMS = \sqrt{\frac{(a - \bar{a})^2}{n}}$$

where:

- a = adjusted coordinate in the photogrammetric model;
- \bar{a} = coordinate of the same point from the survey;
- n = number of points.

In surveying the original statue, a network was realized that is composed of three intervisible stations: the strict least squares adjustment of the measurements made of the *David* provided positions with an accuracy of not less than 5 mm (Figure 7).

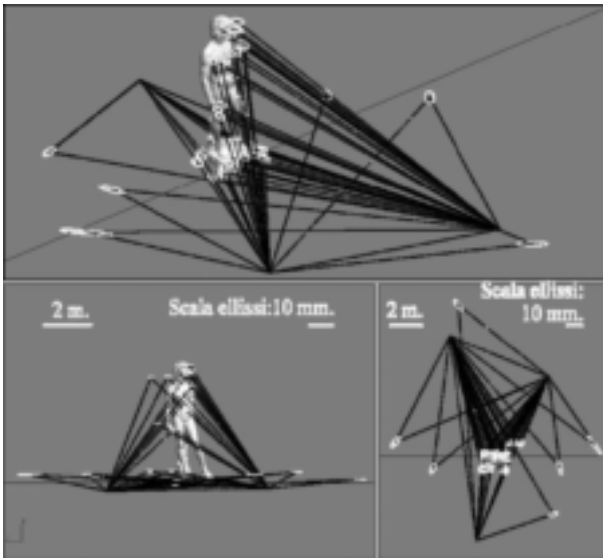


Figure 7. Network of points surveyed in the Galleria dell'Accademia

The collimation of the same points from different stations was facilitated by the use of an infrared pointer, and the points were chosen so that they would be recognizable also on the photogrammetric model. It being an object with an irregular geometric shape, the defining of the sculpture's position is tied to the assumption that its verticality derives from the horizontality of the support base. The base elevations measured show that the statue now stands on a horizontal plane (Figure 8). This arrangement should correspond to the configuration planned and carried out by Michelangelo in 1504, and not to that mentioned in later reports (1874).

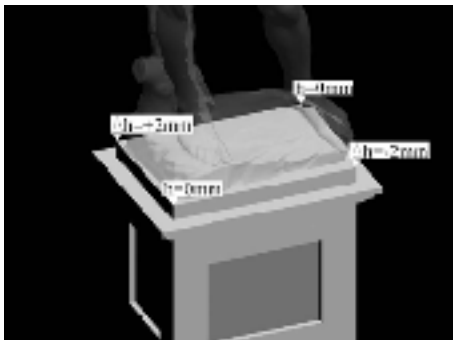


Figure 8. Present-day vertical position of the statue

5. THE DAVID IN THE 1800s

The photogrammetric model makes it possible to find out the three-dimensional coordinates of any point common to two or more frames and thus represents the only possibility for doing a *survey in the past*. The reference system used in the photogrammetric model was modified, interchanging the z and y axes and also inverting the direction of the y axis (Figure 9). The reference regarding the topographic survey was brought into to this new system of coordinates by means of rototranslation. In this way it was possible to compare the two sets of coordinates, having appropriately chosen the points to be considered as corresponding between the system and with which the rototranslation parameters are determined.

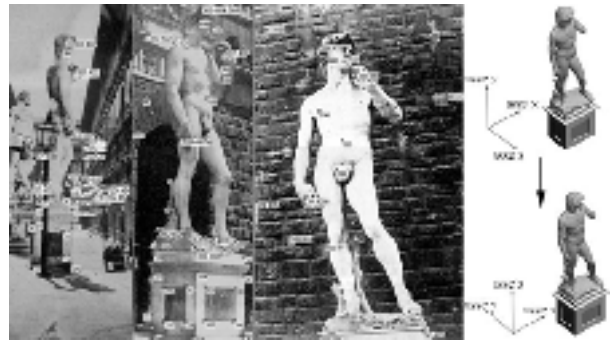


Figure 9. Points surveyed on the photogrammetric model

The supposed rotation of the statue took place presumably due to the sinking of the base foundation. It would have been useful to anchor the two systems at the lower part of the base, but since the base of the statue in the Galleria dell'Accademia is different that that in front of the Palazzo Vecchio, it was necessary to choose points on the lower part of the statue. The rototranslation parameters (residuals less than one centimeter on average) were determined by means of these points (six).

Shift forward of the statue in 1858-'62		
Elevation (m)*	ΔX (m)	ΔY (m)
3.13	0.00	0.04
3.72	0.01	0.01
4.14	0.01	0.06
4.21	0.03	0.07
4.67	0.01	0.07
4.71	0.01	0.07
4.74 (left earlobe)	0.01	0.08

* elevations measured from the statue base surface

Table 2. Difference between the coordinates obtained in the Galleria dell'Accademia and those of the model

The comparison of the coordinates of homologous points made it possible to obtain the differences between coordinates along the x axis that fall within the error range of the photogrammetric survey and that show negligible estimated inclinations in that direction. Along the y axis instead significant differences can be seen that increase with the increasing elevation of the points: the values of the differences between the photogrammetric coordinates and those of the statue in its current position show that in the 1858-1862 period the *David* was inclined forward by about 1° (Table 2). Hypothesizing a probable rigid rotation of the statue with its base and applying the inclination of 1° starting from the lower part of the base, and not from the feet of the statue, a forward shift of about 11 cm at the top can be calculated (Figure 10). The estimate of the statue's forward inclination of 1° in the years 1858-1862 provided by the photogrammetric survey allows one to make useful evaluations of the tensile strength of the marble, particularly in the areas where cracks have been found.

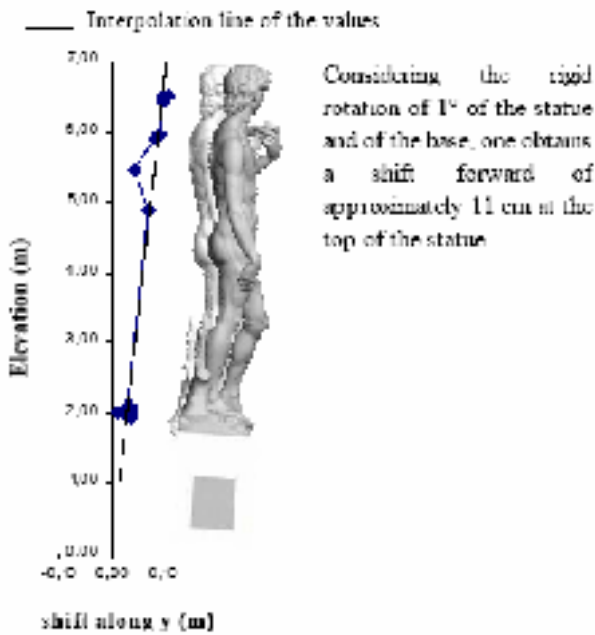


Figure 10. Statue inclination from the vertical in 1858-1862

6. CONCLUSIONS

The study has confirmed the importance of historical images not only as a wealth of information that reproduces the object photographed faithfully and without filters, but sometimes also the only means for analyzing a posteriori, in both qualitative and metric terms, objects of historic-artistic interest which are no longer physically present in their original location. Although the images of the David were not made following the exacting methods of photogrammetry, they possess characteristics that allow them to be used for metric purposes through the use of so-called unconventional methods. Hautmann's sensitivity as a sculptor has provided essential material for being able to reconstruct virtually the sculpture's three-dimensionality through photographs taken from very different angles. This research benefited also from the photographic development and printing procedures based on the contact printing technique, which makes it possible to reproduce faithfully the content of the photograph, and from the good condition in which the photographs have been preserved over time by those who understood their great value from the moment they were made. Despite the limits represented by a definite space of time (1858–1862), by images in which collimation was not easy due to the effect of the albumin, and by the precision of the model, the authors succeeded in identifying and establishing the inclination the statue had before it was moved to the Galleria dell'Accademia. In particular, the estimate of the variation of approximately 1° forward narrows the range of inclination hypothesized by the stability analysis. The photogrammetric survey provides precious information that is useful toward guaranteeing the future protection and preservation of a masterpiece.

This study was carried out as part of the COFIN-PRIN 2004 Interuniversity Research Project of the MIUR, coordinated by Professor Monti of the Politecnico di Milano.

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ACKNOWLEDGEMENTS

The authors wish to thank:
 the Archivio Giorgio Hautmann in Florence for having provided the original contact prints by Anton Hautmann;
 Franca Faletti, Director of the Galleria dell'Accademia, for having given access to the Galleria for the topographic measurements of the David;
 Antonio Borri of the Civil and Environmental Engineering Department of the University of Perugia for his constant and constructive collaboration;
 R. Scopigno and P. Cignoni of the ISTI-CNR for making available the 3D laser-scanning model of the David;
 Gabriele Fangi of the University of Ancona for the high resolution digital photogrammetric scans of Anton Hautmann's original images.