A sustainable geodetic network for documentation and monitoring of the Pantheon

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1. General recommendations for a sustainable network

Documentation of architectural monuments and sites is done with multiple methods like photogrammetry, tacheometry, laserscanning and manual measurement. As a backbone or frame for all measurements in general a three-dimensional co-ordinate network is needed. This network has to have a superior quality and homogenous accuracy (Scherer2003).

The traditional way to establish a network and to work with it is this: Points on the floor of the edifice are marked with durable targets. Over these points a totalstation is positioned and traverses between the points are determined by angular and distance measurements. The co-ordinates are then calculated and an adjustment is made in order to minimize tensions. Based on these co-ordinates the recording may start, using these ground points as stations for instruments like tacheometer or laserscanner. In this second step of the recording the points of interest at the building itself are determined mostly by polar tacheometric measurement. These single points may be used furthermore to combine the point clouds from laser scanning. Or they may be used as targets for photogrammetric work. – So in general there are two separated steps, the measurement and the adjustment of the network on one hand and based on this the determination of points at the building itself on the other hand.

A modern network is established in a very different way. Again it is measured with a total station however no ground points or other artificial points are necessary. The points of the network are exclusively natural points of the building, points which can be expected to be durable, sustainable. Their polar co-ordinates are measured with a free stationed total station. The local networks of these stations are combined by measurements from the different stations to common identical points. So instead of traverses there is a sort of micro-networks measured (see fig. 1).

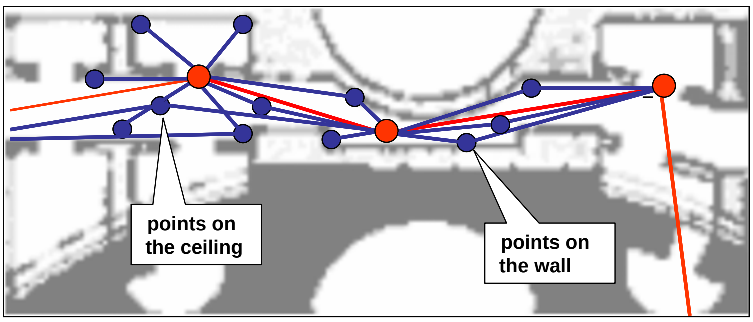

fig. 1: Object bound micro-networks replacing traverses (the red lines symbolise traverses while the blue lines symbolise the measurements to natural points at the walls or at the ceiling).

The micro-network as a whole replaces the traverse. Finally an adjustment is made including all measurements and all point co-ordinates. So not only the polygon points get adjusted co-ordinates forming a homogenous network like in the traditional method but all points. All measurements are made in 3D. As the network is formed by natural points the durability and sustainability are guaranteed. If the network is measured with highest precision the measured points can obviously be used over a very long period of time. The file of known points is available for the densification of the network by free stationing whenever this is necessary.

These are the major advantages of the modern network:

- It is well priced because it is durable.
- It is ideal for all sorts of buildings and monuments because it is gentle and invisible.
- It is available at every place and every time without additional complex and expensive time consuming measurements.
- Its homogenous accuracy makes it usable for many aims also with a view to the future.

In figure 2 the traditional network is compared in detail with the modern network.

characteristics	**traditional way to work**	**modern network**
structure of the network	network built up by traverses ; points at the building in general only tied up to the polygon points by polar measurement; linear polygon of traverses	all points of the same order and with homogenous accuracy micro-networks replacing traverses
marking of surveying points	in general ground points, which are endangered	natural points of the monument itself
measuring mode	forced centring, points of the traverses are to be measured to reflectors in one go	arbitrary stationing every time and measurement of building points with free stationed total station
workflow	sights from point to point	operator has to look at sufficient conjunction of identical points of the different stations
adjustment	only points of the traverse	all points
documentation of the points	co-ordinates and graphical description	co-ordinates and image data-base
use of the network	stationing over the points of the traverses	free stationing

fig. 2: Traditional network in comparison to the modern network

2. The network of the Pantheon

2.1 Realisation and present state

The network of the Pantheon was designed according to the principles described in chapter 1. It is not yet complete, but as far as it is realised its ground plan is shown in figure 3. The network itself is spread over four different levels.

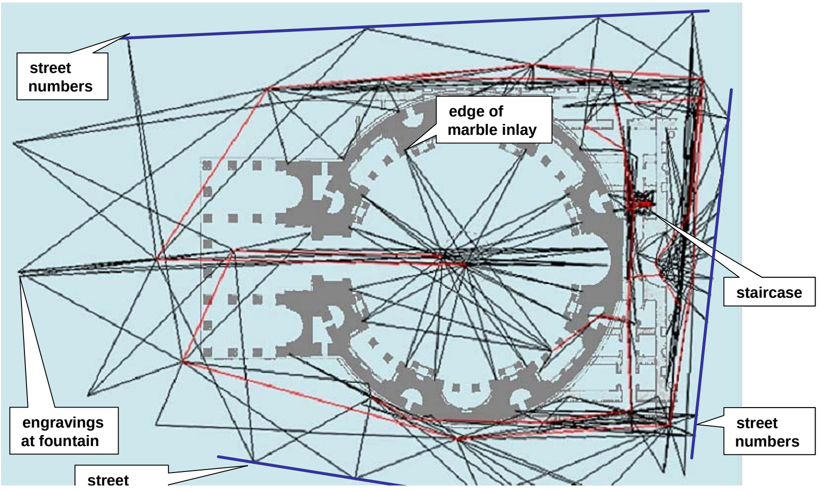

fig.3: Actual precise network of the Pantheon

The natural points as indicated in chapter 1 are realised inside the Pantheon by edges of marble inlay or edges of bricks, outside in general by edges of bricks and street numbers of the surrounding buildings. To enable comparisons between the traditional network and the modern one, both, traditional traverses were measured and measurements to natural points were made to establish the micro-networks. In order to compare both methods directly two different adjustments were calculated. On one side the traverses were adjusted together with all other points (see figure 4a) and on the other side the network was calculated exclusively with the natural points, that means completely without traverses (figure 4b). The resulting error ellipses show that in both cases the accuracy of 2 mm to 3 mm is rather high, especially taking in account that exclusively natural points or simple pads of lacquer were taken as targets. The accuracy attempted without traverses is only slightly worse than the accuracy reached including traverses. The whole network was measured in 3D.

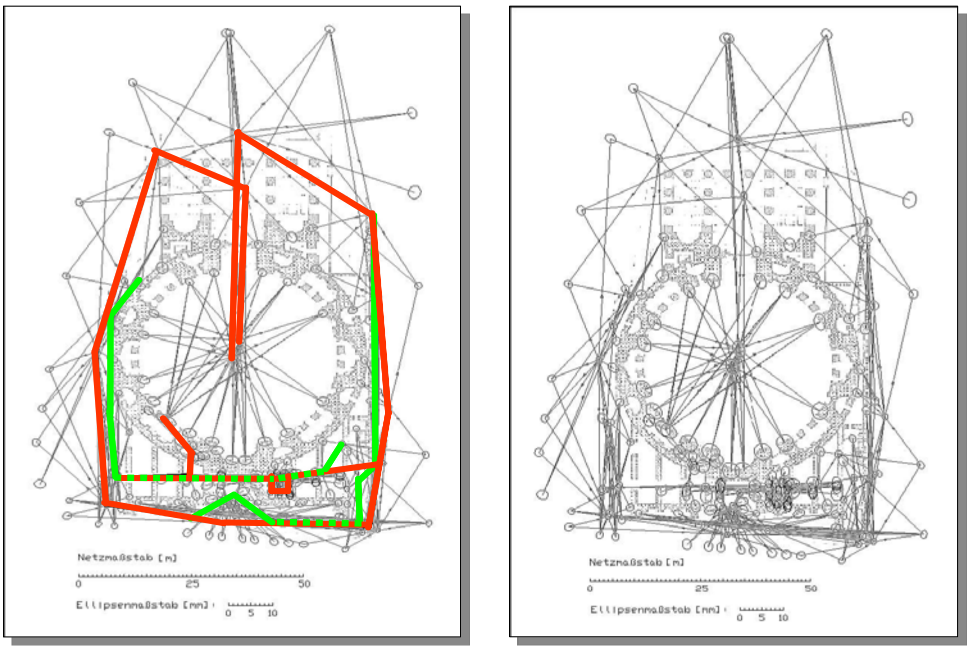

fig 4: Comparison of network accuracy obtained including traverses versus accuracy obtained using micro-networks alone

Although the advantages of the new method are obviously high, there are two demands when establishing the modern network. One is the necessity to have always a sufficient number of points to form the micro-networks – the operator has to think of this - , the other is the fact that working with natural points needs an archive of photos of these points in order to retrieve them later on without difficulty whenever they are needed.

2.2 Ways to document natural points

The natural points were documented either manually by means of a digital camera or automatically by means of a video-totalstation. Figure 5 shows on the left side an image taken with a regular digital camera. The real point was marked in the photo using a computer program. As it is a high resolution image one may zoom in to define and identify easier the exact point. On the right side is demonstrated how to work with a video-totalstation. Photos of the points were taken with the three built-in cameras at the moment when the measurement was made.

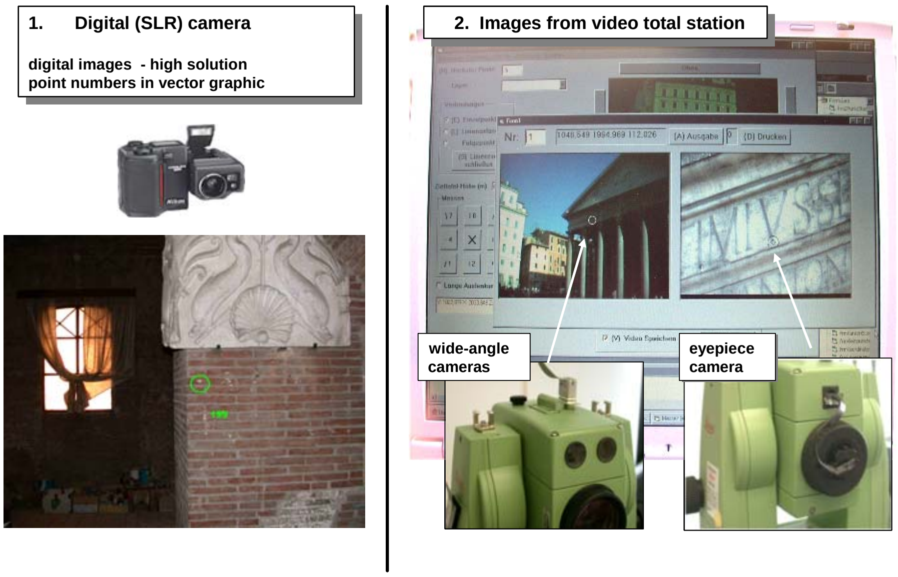

fig.5: Alternatives in documentation of natural points (left: with digital camera, right: using the cameras of the video-totalstation)

Figure 6 gives an impression how archiving can be done using these pictures, taken with one shot simultaneously to the measurement itself. Also the aiming with this instrument was no longer made visually using the eyepiece like in the traditional way. However it was done by means of the photos from the built-in cameras, especially with the telephoto. The instrument was steered by mouse clicking into the image observed and controlled on the screen of the notebook. - Further developments aim at the use of feature extraction to support automatical aiming and matching actual photos with the registered situations archived in the moment when the original measurements were made.

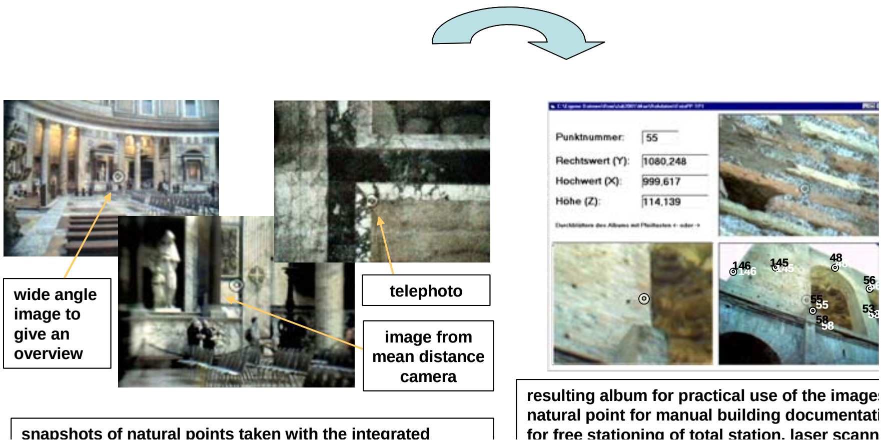

fig.6: Automatic documentation (from wide angle to telephoto) using a video total-station (left); album for the practical use of the images, i.e. for identification succeeded by manual measurements (right)

3. Monitoring and results of deformation measurements

Based on the network some special investigations at the Pantheon were made: measurements of very precise profiles for special analyses, measurements concerning deformations of the dome and first attempts to establish an image archive.

Some results of the technique of very precise so called intelligent scanning (Scherer 2004) are presented in figure 7. Profiles were measured with a point-accuracy of about ± 2 mm. The points are close to each other (i.e. 1cm or 2cm where the distance is measured along the wall) and within a profile of less than 5 mm thickness. Two examples are given. On the left there are two horizontal profiles taken at a column in different heights and one vertical profile of the dome is shown with a section enlarged on the right side. The accuracy of the measurements themselves as well as the correctness within the chosen profile can not be achieved by laserscanning. This is a domain of intelligent scanning.

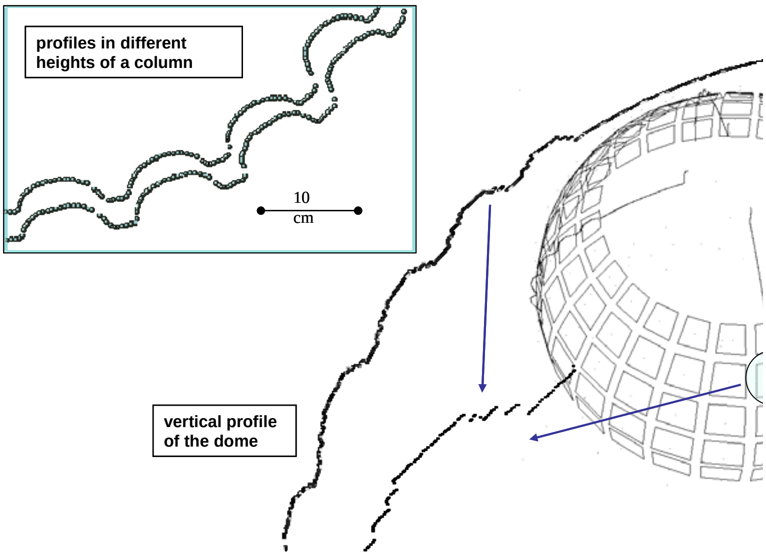

fig. 7: Horizontal (left) and vertical profiles (right) of high precision

Precise measurement of profiles as well as the measurements described later concerning the form of the dome of the Pantheon may be regarded as the so called “zero”-measurements that means as basis for a deformation analysis. The differences between these co-ordinates and those measured at a later date may reveal movements, cracks and so on. So the “zero”-measurements may serve as a basis for monitoring.

In order to gain a better knowledge about the exact form of the half sphere of the dome a network of regularly distributed points was measured with an accuracy of ± 3mm (see fig. 8). From these co-ordinates an ideal half sphere was calculated by adjustment. The radius of the resulting sphere is 43,21m. In the graphical presentation on the left side of figure 8 deformations are not to be seen because they are relatively small. To make deviations from the half sphere visible the differences between the measured points and the ideal sphere were enlarged ten times. The resulting model shown in the graphic on the right side of figure 8 points out some systematic deviations.

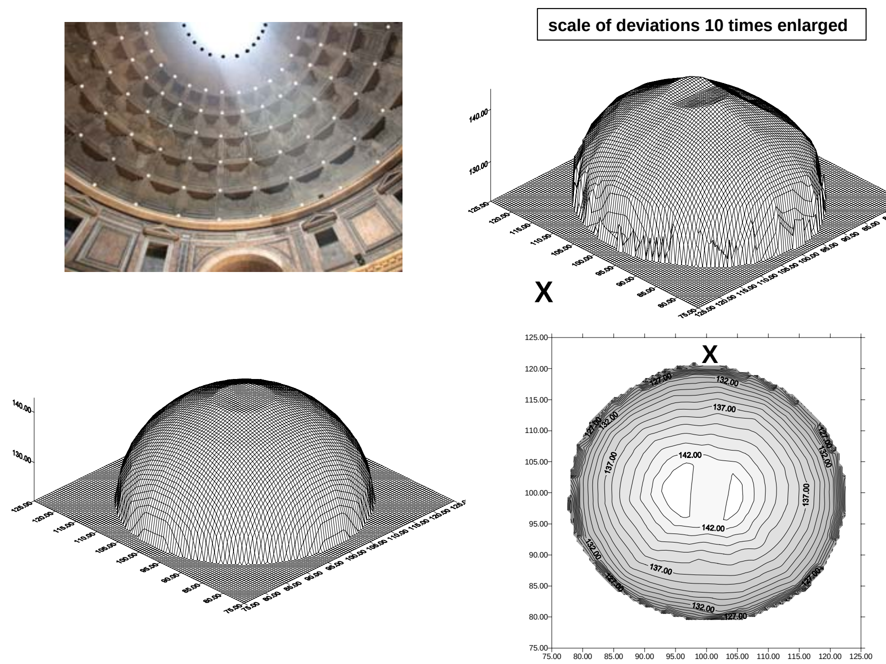

fig. 8: Analysis of the spherical form of the dome

On the bottom of the right side of figure 8 lines of equivalent heights give an impression of the deviations on top of the dome. In order to make also the differences on the sides of the half-sphere more visible the half sphere was developed into a plane according to a mid-distance-conform azimuthal transformation (see fig. 9).

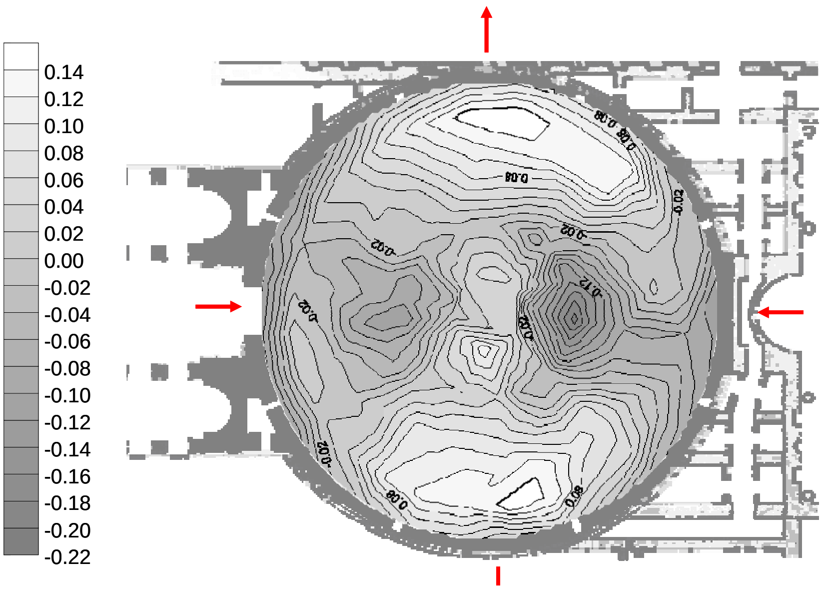

fig. 9: Mid-distance-conform azimuthal mapping of the deviations

The distorting influence of the entrance building and of the building on the back of the Pantheon are to be seen very well. Rotunda and dome seem to be deformed at an amount of about 2dm, obviously caused by the pressure from these buildings.

As a first step towards a more global monitoring (to detect more then only geometrical changes but to detect also other influences on the building) a set of colour and black & white images of all cartridges of the dome was made. As demonstrated in figure 10, photos taken at more or less regular time intervals enable to detect changes f. e. caused by water bearing gaps.

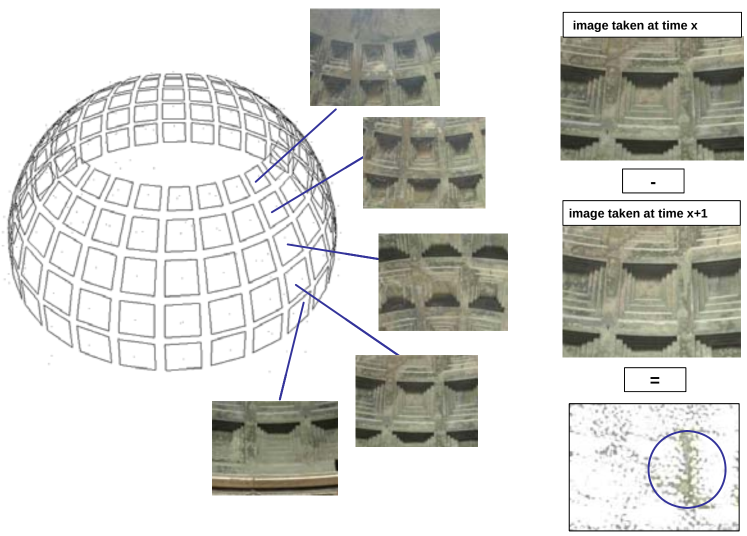

fig. 10: Demonstration of monitoring possible by differential analysis of images taken at different times

This might be the beginning of a modern system for differential analyses of all sorts of changes, i. e. to detect mechanical deformations, influences of humidity, fungal decay or chemical influences.

4. Conclusions

It could be shown that a network of natural points which are forming micro-networks instead of traditional traverses has many advantages. It may serve as a basis for all sorts of documentation work, for deformation measurements, for monitoring and of course also as the backbone of a monument information system (MIS). An archive of the images of the natural points was established enabling to make use of these coordinates of high precision in future. The network has still to be completed and a final adjustment has to be made. The resulting data base of sustainably usable co-ordinates should be open for all futural users. Based on the MIS a monitoring concept would be helpful supporting a sustainable management.

5. Thanks

Above all I thank Dr. M. Juretzko for the measurements with the video-totalstation, for calculating and presenting the adjustment of the network and the deviations of the dome. These results are part of his thesis improving the high quality attemptable using a video-totalstation (Juretzko 2005).

6. References

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