

## OUTLINE / INTERPRETATION

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### ABSTRACT:

The different technologies used to observe the visible aspects of an architectural work produce various kinds of knowledge. The choice of a specific method of geometric analysis gives an interpretation of the object. The conveyed information is not neutral. It depends on the contents of the survey project, on the use of different techniques and measuring instruments. Nowadays the technological progress is centred both on the improvement of systems capable of implementing data and the necessity of handling models of representation using automatic numerical procedures. Digital photogrammetry and laser scanning aim at a complete description of the work. This description is based on an accurate reproduction of figural and spatial elements, which are transmitted by the codes of the projective geometry. The need to overcome the partiality of the cognitive *iter* and the desire to understand only the work's metrical features call for a deep reflection about the object, the instruments and the outcome of the survey. Modelling the Cartesian space doesn't exhaust the knowledge of the construction; many architectural authentic qualities are not considered in a quantitative reading. Any measurement or representative operation is necessarily selective considering the multifaceted nature of reality, being also strictly linked to the meaning the operator intends to confer on his actions.\*

### 1. INTRODUCTION

Often a survey operation aimed at an in-depth knowledge of an architectural work is carried out in two different directions which are only apparently contradictory: the first is that of a quantitative measuring of the visible aspects of the building; the second is that of a qualitative evaluation of its many morphological aspects.

Indeed the spaces and elements of architecture can be studied, firstly by documenting the geometrical dimensions through "objective" measurements expressed in numerical form; but an architectural work can also be investigated, or measured using other parameters such as the chemical-physical nature of the materials used and decay phenomena, the chronological sequence of its parts and temporal events of the cultural context, the theoretical statutes of the project and the technical statutes of its construction (Ugo, 1993).

The restitution of data from the metrical survey may be a good starting point for the integration of the two cognitive studies: on the one hand the graphic charts fully describe the geometrical space in which the characteristics of the work appear; but they are also the frame of reference for various "events" which have occurred in the past, related by a sharing of common spatial parameters. The survey model thus joins together forms of knowledge from various disciplines; it is a way of connecting scientific data from non-destructive studies and discursive interpretations from historical or critical spheres.

The above defines the theoretical and scientific thinking that underlies this survey and the conclusions dealt with here as regards the western façade of the church of the Certosa monastery, Pavia.



Figure 1. Front view of the western façade of the Certosa monastery, Pavia (photograph by Fiorenzo Cantalupi, Pavia)

This research study, on behalf of the Council for Architectural Works and Landscapes of Milan, constitutes part of restoration work on this façade and involves the acquisition and elaboration of data in order to study geometrical and morphological facts in detail: data related to dimensions, geometry, morphology, and the colour of the materials which make up the external face and lateral parts of the façade. The realisation of these aims is based on the use of the most advanced procedures in the field of digital photogrammetry, but also entails the experimental use of the latest techniques in laser scanning.

\* The work presented here is ongoing at the Laboratory of Morphological and Modelling Analysis directed by Professor Vittorio Ugo; the research group is made up of Giovanna Battaglia, Maria Cristina Bonora, Federica B. Cavalleri, Cristina Pellegatta with Gabriella Garelo (University of Genova) acting as external consultant. The group also avails of the assistance of Professor Gabriele Fangi and Professor Eva S. Malinverni (University of Ancona) in connection with the integration of digital photogrammetry using the latest techniques in laser scanning.

The elaboration of geometrical data has first and foremost produced an accurate description of its condition: from the three-dimensional digital model derives an image on a scale of 1:50 of the overall view of the façade, as well as an image on a scale of 1:20 of the view of the lower section, between the base and the cornice above the portal, complete with vertical and horizontal sections.

The spatial model created using the CAD system is also however the basic structure on which the “themed” computer models are designed. From the point of view of graphic images, the diagrams with metric content (scales 1:50 and 1:20) become the basis on which “thematic maps” related to the object are drawn up. Through these maps, one can see the entire results of other analytical studies, related to the materials (stone, mortar, metal components), any substitutions made in the course of previous restoration work, the degree of conservation and macroscopic forms of decay, as well as the project specifications related to the building work in progress.

Apart from this type of description and interpretation there is also another one, linked to experimenting a “geo-referenced” database connected to the three-dimensional model; this integrated computer system, which is effectively organised and meets the criteria of diachronic and synchronous reading, permits the various personnel involved in restoration work and researchers to set up specific surveys according to their needs. On the basis of this principle, G.I.S. has also added the storing of digital images of the building: a real “media gallery” which stores all the photographic documentation, both general and specific, that was collected during the course of both the survey and the bibliographical and archive research.

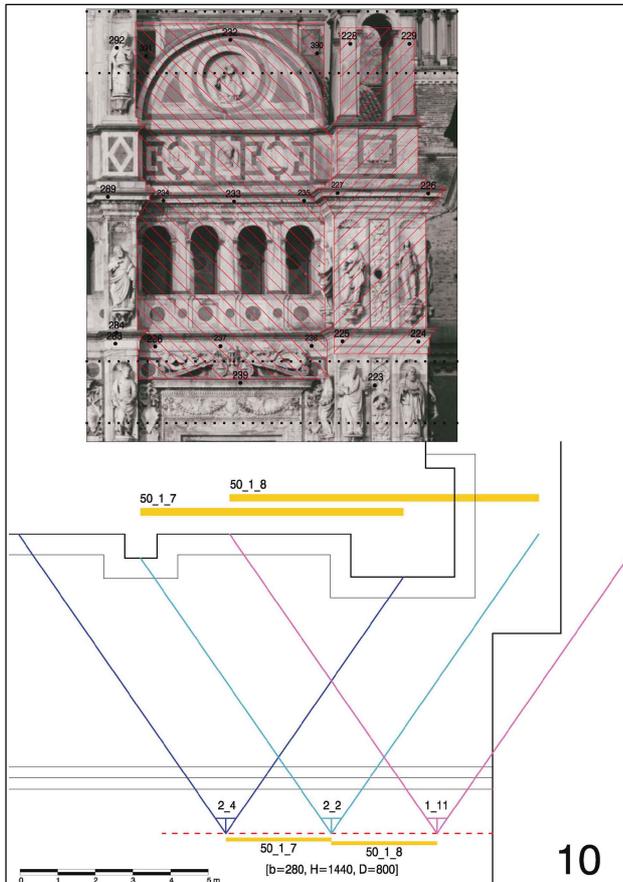


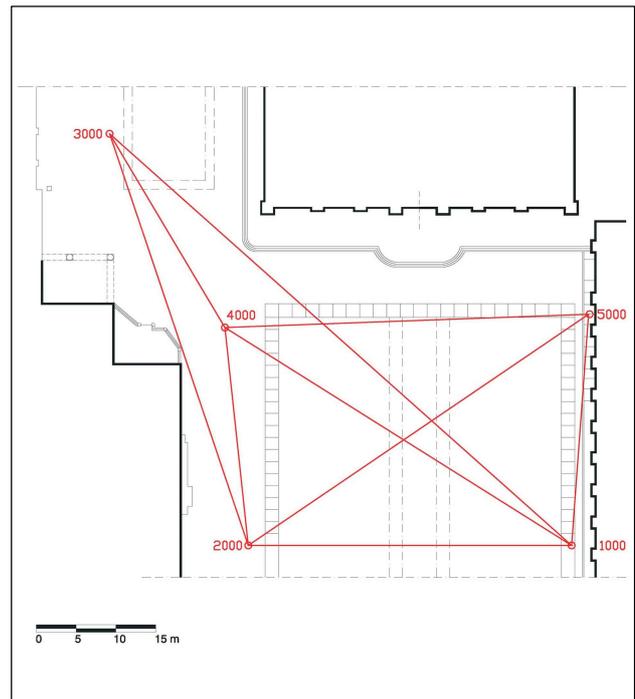
Figure 2 (right). Layout of the topographical polygonal Figure 3 (top). A plano-altimetric diagram of the project including data about the shots taken for the restitution of the façade on a scale of 1:50

## 2. THE ACQUISITION OF GEOMETRICAL DATA

### 2.1 The photogrammetric mapping project

The acquisition of metric information is based on a five vertex topographical polygonal, whose geometric pattern can cope with the need for optimisation of subsequent measurements for forward intersections and polar co-ordinates, which serve to measure the markers of the photogrammetric shots. The polygonal traced out in the garden in front of the façade has permanent bench marks made of cippus markers or non-protruding embedded topographical rivets: a monograph is drawn up for each vertex which allows them to be located easily. As already mentioned, the stereoscopic models deal with the need for restitution on a scale of 1:50 and 1:20; in general the acquisition of the models is carried out “by objects”, avoiding as much as possible splitting up the elements of the façade, while at the same time adhering to the pre-established longitudinal and transversal covering values (longitudinal covering between contiguous photographs of the same flight strip 55÷65% of the side of the photograph, transversal covering between contiguous photographs of the same flight strip greater than 90% of the side of the photograph, transversal covering between photographs of adjacent flight strips greater than 15% of the side of the photograph). The photographs for the restitution on a scale of 1:50 have the following characteristics: average scale 1:200÷1:250, field of view 11x11m, shot distance approx. 8m, base of shot 30% of the distance, height of shot 5-14-24m. The photographs for the restitution on a scale of 1:20 have similar characteristics: average scale 1:80÷1:100, field of view 4x4m, shot distance approx. 3.2m, base of shot 30% of the distance, height of shot 2-5-7-9-4-13m.

The topographical markers for the models are created using removable artificial surveying markers which are numbered in progression: they are self-stick markers with a “chess board” design and have optimised dimensions as regards the two scales of the photographs (3.5x5.5cm e 5x7cm). The distribution of the points on the façade takes into account the area included in the shot in such a way as to always have at least four 3D charts for every photogrammetric model, thus ensuring an accurate evaluation of the reliability of the absolute orientation work.



## 2.2 The surveying field-work

The topographical and photogrammetrical work was carried out in May 2002 and a team of on average four people was involved. The measurements of the polygonal and the topographical points were taken using a Topcon GPT 1001 total laser station: theodolite with direct reading at 5cc, electro-optical diastimeter with s.q.m.  $\pm(3\text{mm}+2\text{ppm})$ , precision without prism  $\pm 5\text{mm}$ ; from each vertex the angular direction measurements (azimuthal and zenithal) are taken in the two conjugate positions of the telescope whereas the distance measurements are repeated at least twice. The spatial positions of the marker points set out on the façade according to the project specifications and noted on the field drawings are taken by forward intersection from the base and polar co-ordinates, depending on whether they are points on the face or on the lateral parts. Identification of the two sets is facilitated by the codes included in the field books.

The photogrammetric shots were taken using EPR Ektachrome 64 film and a 9-reseau semi-metric Rolleiflex 6008 camera with a Zeiss Distagon 4/40 H lens, mounted on a Manfrotto Triminor 055CB tripod (standard 3D M029 head). All of the models, apart from those related to the sides of the base strip, were obtained from the platform of a trailer mounted hoist, having first mapped out on the ground the distances specified in the project and having checked the coverings required.

The survey includes non-metric photographic shots, both overall and detailed, of the counter-face section above the roofing and of the south face which was inaccessible for photogrammetric surveying. It also includes photographic documentation of the external face through perspective views of the architectural elements, with particular attention to the linking devices between the constituent parts. A Nikon F-401s reflex camera (with Sigma 24mm, Nikkor 35-70mm and Sigma 70-210mm lenses) and a Nikon Coolpix 995 digital camera were used.



Figure 4 (top). The shot from the aerial platform of the “frontal” views for restitution on a scale of 1:20  
 Figure 5 (bottom). The stereoscopic pair of a model for restitution on a scale of 1:20

## 2.3 Data processing

All the topographical measurements were calculated using Geopro Meridiana 250 software. The general framing polygonal is calculated plano-altimetrically through rigorous compensation procedures to the least square, assuming an arbitrary starting point and orientation which identify the local reference system; the program supplies the compensated value of the co-ordinates of the network vertices (X, Y, Z), the s.q.m. of the co-ordinates themselves and the error ellipse parameters connected to each vertex. Once the spatial system reference has been established, the tacheometric calculation of the 3D co-ordinates of the model reference charts is worked out and lastly the superfluous metrical information is selected.

The photograms, which are put in order and catalogued following the field books and the project diagrams of the stereoscopic pairs, are transferred to digital form through direct scanning of the films, using a Vexcel UltraScan 5000 calibrated photogrammetric scanner. The scanning is carried out at a setting of 2000dpi resolution: thus the dimensions of the image pixel (0.0127mm) correspond to the dimensions of real pixel equal to respectively 1.2mm for the photograms on a scale of 1:80÷1:100 and 2.8mm for those on a scale of 1:200÷1:250.

## 3. RESTITUTION OF GEOMETRICAL DATA

### 3.1 Orientation of the models

The perspective shots are processed for metrical purposes using Geopro RFD Evolution 152 digital photogrammetric software, which permits restitution in stereoscope. As soon as the relative and absolute orientation calculations for each pair of photograms are concluded, the operator can proceed to direct visual exploration of the relative parts of the façade on the virtual model; even the commissioning clients can use this remarkable cognitive instrument if they have the necessary hardware and software at their disposal. The oriented stereoscopic model can in fact be opened up at any time and interpreted visually; this has been defined as a “stereo-photo-chart” (Dequal, Lingua, Menci, Rinaudo, 1999): a special cartographical drawing which is able not only to supply any dimensional data directly onto the 3D model, but also to document the qualitative characteristics of the building at an interactive level that is far superior to that of the rectified image and the ortho-photomap.

name	type	North co-ord.	East co-ord.	height
1000	fixed	0.0000	37.8770	-0.0524
2000	fixed	0.0000	0.0000	0.0000
3000	comp.	48.6071 $\pm$ 0.0009	-16.2480 $\pm$ 0.0005	-0.0106 $\pm$ 0.0004
4000	comp.	25.7231 $\pm$ 0.0004	-2.7369 $\pm$ 0.0003	-0.1469 $\pm$ 0.0003
5000	comp.	27.2929 $\pm$ 0.0004	39.9819 $\pm$ 0.0003	-0.1245 $\pm$ 0.0004

point	X mod	Y mod	Z mod	parall.	X res	Y res	Z res
237	104.9610	94.6827	-227.7021	-0.0002	-0.0009	0.0004	0.0005
243	-16.6239	-131.1573	-233.8117	0.0027	-0.0037	-0.0003	-0.0020
240	34.2481	-76.4620	-234.8815	-0.0032	0.0057	-0.0023	0.0000
239	122.5347	21.1521	-212.8267	0.0025	-0.0005	-0.0014	-0.0041
244	123.8571	-130.4972	-281.3561	0.0022	-0.0009	0.0024	0.0033
236	0.3131	96.8756	-226.0407	0.0034	0.0003	0.0011	0.0022
5	-35.3142	35.7360	-229.1893	-0.0034	0.0000	0.0000	0.0000
6	132.3759	128.9304	-233.9245	-0.0016	0.0000	0.0000	0.0000
7	21.9699	13.0453	-234.6697	0.0003	0.0000	0.0000	0.0000
8	91.3185	-171.5839	-293.5809	-0.0017	0.0000	0.0000	0.0000
9	153.6058	-60.7697	-236.4133	-0.0012	0.0000	0.0000	0.0000
10	32.3381	128.2936	-231.8210	-0.0001	0.0000	0.0000	0.0000

Table 6 (top). Topographical polygonal: compensated co-ordinates  
 Table 7 (bottom). The residual values of the relative and absolute orientation of the model in figure 5

### 3.2 Stereoscopic and monoscopic restitution

The stereo-photogrammetric restitution is aimed at “delineating” the various elements according to a specific priority criterion: firstly the stone blocks that define the structure of the wall and its decorative features, then the details concerning the constructional logic and unforeseen events (substitutions, inconsistencies), and lastly the figurative features which are rendered with “true-to-life” graphics that are as good as, if not better than the standard definition of the scale of representation required. In fact restitution on a scale of 1:20 enables you, for selected parts only, to obtain printouts on a scale of 1:10. Such a structured restitution results in the correct interpretation of the relationship between adjoining elements and allows for the analysis of what is present and what is absent, as well as unusual features and repetitiveness. The fact of having the design in separate sections also enables you to attribute specific characteristics to the various graphic features, both in the construction of the 3D model and in its thematic re-elaboration.

In the sections of the façade with a similar structure to the flat surface, it is possible to operate using digital straightening procedures: the photogrammetric software used to create the rectified images is the Rollei MSR 4.0 and the projective transformation utilised the information gathered from the stereoscopic models. Then the metrically corrected images are inserted into the “wire frame” model in order to undergo the vectorial re-drawing of the designs engraved in the stone.

The field reconnaissance allows for the integration and testing of the restitution drafts. This involves firstly evaluating the drawings to identify and correct any gaps or interpretative errors, then proceeding to direct mapping of those details which are incomprehensible on the photograms due to their position in shaded areas, or on very dark surfaces or because they are physically out-of-sight in the shot. Then metrical checks are carried out in order to record deviation between restitutive measurements and measurements that have been acquired directly: the values of the distances of 4÷6m are roughly 0,5÷1cm.

### 3.3 Construction of the 3D model

The whole sense and outcome of the survey lie in the area of representation, as a historically (theoretically and scientifically) founded activity on a level with any planning activity; the “internal design” of the object expresses itself in an “external design” which falls within in the area of execution procedures of design techniques, in which however each outline indicates something else (Pierantoni, 1998): the model of the object is also based on conceptual categories and parameters of a topological nature, and not only on the apparent aspects governed by the rigorous application of the rules of descriptive geometry.

The assembly of the metrical restitution and the editing of the spatial, vectorial and raster model is carried out using AutoCAD 2000i and AutoCAD Map 2002 automatic design software; the graphic images are printed on a HP 2500CP ink jet plotter. All the numerical designs, created for graphic features, are imported to a single file and the information is structured in thematic areas, in such a way that it is possible to select the features themselves in relation to their general or specific characteristics. The file contains approximately 40 layers, including temporary ones related to the various stages of work. The general categories of objects, as well as the parts or detailed elements, are organised in relation to the architectural and sculptural analysis on the two scales of 1:50 and 1:20. Currently, the design file is proving to be easily manageable, in that it refers only to the “right-hand fifth” (furthest right of the five vertical sections). In order to avoid excessive difficulty, the creation of a graphic model for each one of the five vertical sections of the façade has been planned.

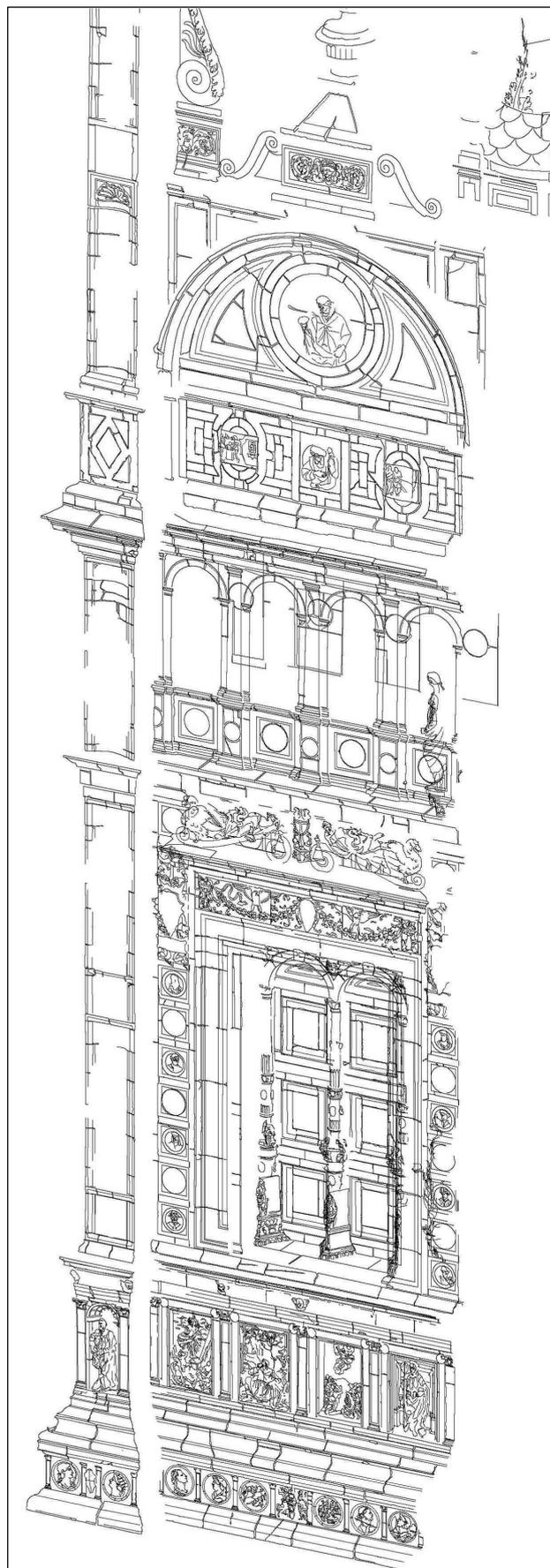


Figure 8. The “right-hand fifth” of the façade: axonometric projection of the restitution model (original on a scale of 1:50)

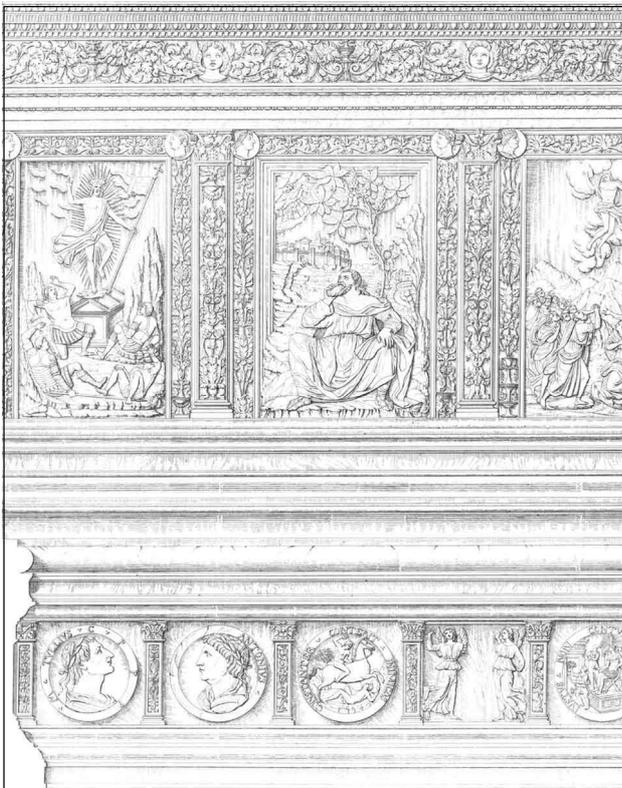
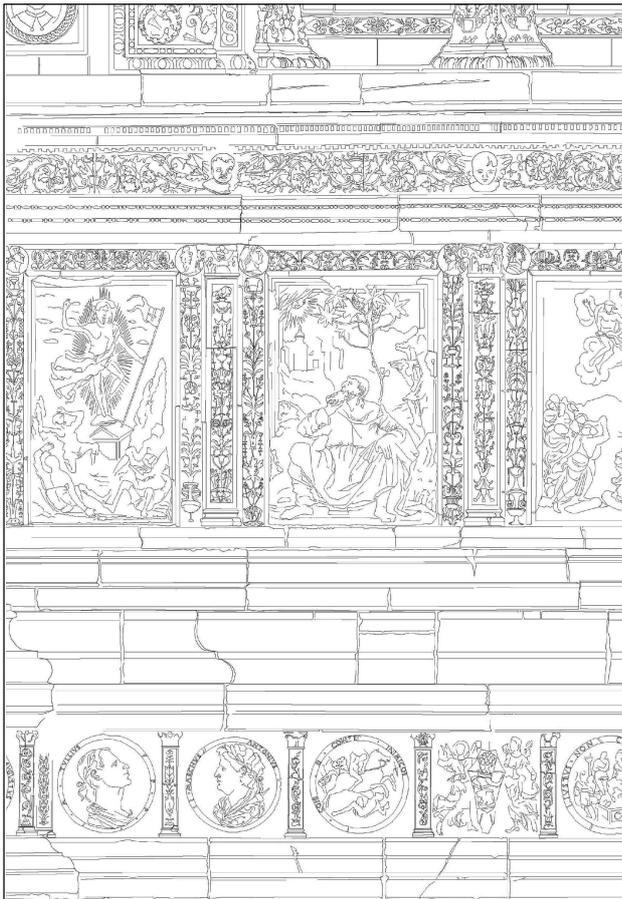


Figure 9 (top). The base strip of the “right-hand fifth”: orthogonal projection of the restitution model (original on a scale of 1:20)

Figure 10 (bottom). The base strip of the “right-hand fifth”: engravings by Durelli from the second half of the 19<sup>th</sup> century



Figure 11. The window of the “right-hand fifth”: orthogonal projection of the restitution model (original on a scale of 1:10)

#### 4. THE STORING OF DIGITAL IMAGES

The images created by the stereoscopic and monoscopic restitution work were put into a database of digital images currently being set up, the results of which will be integrated with subsequent GIS experimentation.

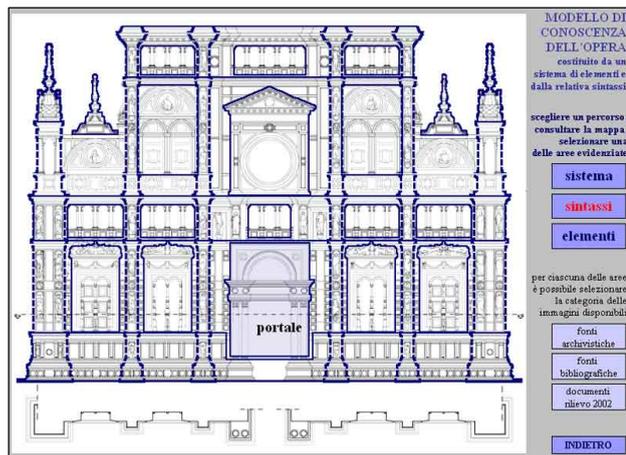
This database, which consists of an easy-access record, is intended to be a non-metric model of information about the building, a description of its entirety and its individual parts based on the possibility of simultaneously consulting varied documentation from different historical periods.

The archive is based on the singling out of “elements” that make up the façade and on the interpretation of the relationship between them; the inputting and cataloguing of the images as well as the “surfing” of the database itself, meets this criteria of “syntactic reading” of structural and expressive values of the building, seen as a system of elements governed by precise syntax. Currently the images included derive from bibliographical sources, archives and material collected during the course of the survey: the filing and consultation of the various documents is based on two closely connected systems. Microsoft Access 2000 was used for the design and graphic interface.

The first system uses spatial characteristics as access keys to the entire data: elements, parts and orders of the façade are highlighted on “sensitive maps” from which you can select the various points, thus accessing all the images connected to the analysis; the intuitive surfing of the maps allows a rapid consultation of the iconography.

There are three consultation routes planned and therefore three “sensitive maps” connected to the three browsing keys of the façade: system, syntax and elements.

The second system involves direct access to all the organisation and management files of the data connected to each image; it includes a “research” mode which allows you to obtain a selection of images on the basis of the requirements entered in the appropriate spaces in the file: the system helps the user to do this by supplying a list of possible terms for each space. The research spaces are related to the category of the image, the key words, which of the different zones on the three sensitive maps it belongs to and lastly the spatial position. The image file offers two further possibilities: a link to a bibliographical file related to the book from which the image is taken and lastly a high-resolution printout of the document.



<b>syntax</b>	horizontal syntax	lateral conclusion / partition
	vertical syntax	upper conclusion / relation to the ground / lower - upper transition
<b>features</b>	internal-external relationship	windows / blind windows / main central window / loggias / small loggias / portal
	architectural features	double lancet windows / columns / cornices / aedicules / pillars / pinnacles / tympana / trabeations
	sculptural features	high relief / bas-relief / candelabrum columns / medallions / busts / statues
	decorative features	tarsias / volutes

Figure 12 (top). One of the “sensitive maps” of the façade, related to the “syntax” key  
 Table 13 (center). Table of values related to the “syntax” and “elements” fields  
 Figure 14 (bottom). Left half of the data chart compiled for each image in the archive

## 5. CONCLUSIONS

An architectural survey poses problems which go beyond the mere “technical” content of measurement and pure illustrative function, since the geometric universe it deals with is not just a Euclidean grouping of points and lines to be transcribed onto paper through a graphic and/or numerical language. This universe is rather, a “form of communication” between the “figures” generated by a design concept, those materialised through an executive rationality and lastly those included by chance. The completed, orderly whole of the geometry of the architectural work is an important record of the different forms of knowledge that produced the building. Equally important are its transgressions and anomalies, the decay phenomena and the unforeseen events. The topographical-photogrammetric procedures and the computerised re-workings are powerful investigative means which simplify some aspects of the surveyor’s work through the “automation” of many operations but the use of technology must be sustained by scientific and theoretical thinking, if one wants to understand the physical body of the monument as a “evidence” of a civilisation and era. This means for instance that we have to break away from a Renaissance theoretical construction which takes the image, including photographic images, to be the essential data. The image alone, albeit filtered of its geometric interpretations, cannot entirely convey the complexity of a piece of work: constitutive “components” of a deliberate syntax, “fragments” that are witnesses to unforeseen accidents, “parts” capable of establishing formal hierarchies and characterising “types” (Ugo, 1991). The study of the volumetric and morphological aspects must go from what is visible to what is not: the investigation of the “empty” spaces must be completed by that of the solid “full” areas, the surface data of the form as “image” must be enriched by layered data in the form as “structure”. In the area of restoration, what is “not visible” is the operative field of diagnostic non-destructive techniques, whose instrumental apparatus investigate not only the constructional characteristics and the materials but also the stress the individual parts are subjected to, the forms of physical and chemical decay. The invisible however, is not just a materiality which hides itself from view: technological systems, static equilibrium, historical and social facts and in general all the aesthetic values and the theoretical statutes of the building are “invisible” by nature.

## 6. REFERENCES

Dequal, S., Lingua, A., Menci, L., Rinaudo, F., 1999. Il navigatore 3D per la gestione simultanea di più modelli stereoscopici dei centri urbani. In: *Atti del 3° Congresso ASITA*, Napoli, Vol. I, pp. LXXVII-LXXXII.  
 Pierantoni, R., 1998. *Verità a bassissima definizione*. Einaudi, Torino, pp. 27-34.  
 Ugo, V., 1993. Dar da vedere, misurare, o conoscere? *XY-Dimensioni del disegno*, 17-19, p. 10.  
 Ugo, V., 1991. *I luoghi di Dedalo*. Edizioni Dedalo, Bari, pp. 113-140.

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