

## ENGLISH VERSION

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### CONSTRUCTION TRADITIONS AND RESTORATION

Some restoration architects have alluded to the need to go back to the construction methods of the past to use them as reconstruction methods in keeping with the historical truth of the fabric. In any case, to satisfy this need, it is worth asking the following questions: are we in a position to dig up the old rules of art in order to recuperate trades and their technical and constructive skills? What does the so-called constructive tradition consist of? To what extent does this tradition still belong to us, or is it unfamiliar to us?

Any answer to these questions involves first trying to define the term tradition, at least as far as building is concerned, and finding out whether its survival and effectiveness are still valid. To begin with, let us say that the thesis sustained in these notes is that tradition, linked to the transmission of long-lasting experience, went into crisis with the changes that Western culture underwent after the birth of the Modern World, which many authors consider to be the arrival of Humanism. In particular, the decline of tradition seems to be connected, above all, with the advent (and development) of the new science, the constitution of a different conception of history and the changes in production techniques and methods.

#### *Tradition / Experience*

The meaning of tradition, as it used to be understood in olden times, can be found by resorting to a singular rule taken from Vincenzo Scamozzi's *L'idea dell'architettura universale* (The Idea of a Universal Architecture): "It is a good sign if when we rub two stones together they become crushed and give off a sort of dust and smell terrible and taste somewhat false. Big heavy ones are better than small light ones, because they have greater virtues and give strength to the lime; and finally those that are alive and have great nerve."

The singularity resides in the way Scamozzi suggests we choose a good

stone for making lime by using all our perceptive senses. But this precept, to be properly understood, requires a general predisposition to comprehend, based on experience: only someone who has listened and tested over a long period of time has a good criterion to grasp its meaning completely and realise how useful it is. Having recourse to perception is based, therefore, on the body of knowledge transmitted partly by distant sources and partly acquired through one's own work and observation. In other words, there is a guideline for transmitting old experiences to new generations, in a chain of notions handed down from father to son, from master to apprentice. As a result, the transmission of knowledge is connected with certain conditions: a) the credibility of the person who formulates the message, embodied by the recognised figure of the master; b) the line of continuity that connects the master's experience with successive and previous generations; c) the acknowledgement that the real meaning of the message and its efficacy can be understood only by those who are members of the trade, by those who possess the conditions and experience of art; d) the possibility or opportunity that the message may be formulated in essential terms in order to safeguard the esoteric aspect that makes it wholly comprehensible only to those who have the talent and the status of initiates. Experience "is based on memory", as Aristotle said, and constitutes an accumulation of notions taken from reality essentially through the senses, which, for that reason, except in the case of false perceptions, are endowed with guaranteed credibility.

#### *Tradition / Science*

In any case, Scamozzi lived and worked at the dawn of the Modern Age, which would give birth to a new vision of technical and scientific knowledge rather than a different way of measuring oneself with the past, of measuring oneself with history. In other words, the signs of a general change in culture are already present, and, above all, experience is becoming replaced more and more frequently by experiment. It is not a mere verbal trick: the ways of observing and conceiving reality change. Experience, in fact, presupposes in whomever possesses

or transmits it a gestation of inner knowledge, conserves the intimate character of an individual manner of relating to things, and presumes that things actually exist and are the real object of speculative and operative action. On the contrary, experiment transforms repeated essays into an exercise of reasoning that needs to be controlled and shared by the whole community of experts. It requires the presence of "spectators" and is, we could say, the *mise-en-scène* of technical and scientific elaboration, its public entry into the circuit of mundanity.

The new science sought the logical order hidden behind the casual appearance of things, according to the model established in Ancient Greece which in time was destined to spread to everyday events and the actions of the ordinary man. In this way, things lose the contingency of their concretion little by little and take on the status of representing these laws, that is, a reality that transcends them in their condition of sensorial objects. What comes to mind is the falling apple observed by Newton. In the story, the fruit seems to lose smell, taste, shape and colour to become the pure manifestation of gravity, an abstract dynamic phenomenon. With the realm of *experimentum* substituting the realm of *experientia*, science establishes the conditions to modify the order governed by tradition.

There is, for example, a formula of Pliny's that involves the preparation of lime mortar slaked with wine with the addition of "pork fat and figs, both of which are mellowing agents". Fifteen centuries later, the recipe is still widely known and Baltasar Peruzzi reminds us, "In olden times people used to make mortar with fresh lime slaked with wine and then mixed with pork fat and dried figs."

Today, we are a long way away from the central strand guiding this way of thinking, but we have learned from science that this alchemistic procedure has a logical explanation and, in the preparation of some mortars, we do add fatty substances to make them easier to handle without increasing the amount of water. Sugar can also have a fluidising effect and current research is attempting to throw some light on the influence of fermentation, whose action has not been experimentally confirmed in the setting process.

The ways of tradition find a principle of contamination in science. The development of a rationally based cognitive system gradually tends to lay aside the role of individual experience until it becomes alien to the preponderant line in a modern world. The very formation and propagation process of technical culture is challenged: in fact, the demonstrative value of scientific proposals is different from the persuasive value of experience; the repeatability and refutability of the experiment are different from the trial and error process that involves the obvious evidence of the senses and human memory. Besides, the former presuppose an interest in the general laws that govern phenomena and require knowledge to be put down in writing; on the other hand, the latter is based above all on the defence of the spoken word, on practice and on the evident testimony of things. And what is more, the progress of scientific conquests is verified by means of a propagation in a complex network of interactive relations that invade the multidimensional space of culture, aspiring to imply all thinking beings; empirical procedures, on the contrary, are affirmed in a linear direction, along which the experiences of individual subjects belonging to the same art or trade are gradually added link by link.

#### *Tradition / History*

Individual experiences involve memory, observation and executive capacity guided by certain rules, and the rules are established by those who have in turn had similar experiences, that is, by a trustworthy subject that assures us they are reliable. In this way, the mechanism of tradition induces the actors to perceive their own present as anchored to a more or less recent past, in an endless chain of “recent pasts” that follow a peculiar diachronic route. The chain metaphor gives us the idea of a succession of rings where the concepts of before and after are laid out according to their contiguity order rather than the logic of their development. The norm of contiguity even extends to future actions, also located in a “near future” that is seldom longer than the span of a single generation. Thus “long ago” is a category of time ignored by tradition. For tradition the past is not yet history, but possibly a witness and example or “promise of return”, and the future is

never a project, but rather a destination or goal of Providence.

In its linear development, the transmission of experience is therefore performed between contiguous subjects, one before and one after. One of them speaks directly to the other, and this one participates wrapped in a contemporaneity broadened by the rite of listening. It is not by chance that “tradition”, which comes from *tradere*, means “give” or “deliver”, according to Cicero, with the meaning also of “trust”; it also means “explain”, “narrate”, “refer”, “show” or “transfer” or “transmit”. In all cases, *traditio* involves the direct passing, from him who goes before or comes after, of a certain legacy of ideas and experience, and implies that transference is possible thanks to the immediacy of the relationship between the person who transmits and the one who receives, in a time that encompasses and comprehends both actors and action. We can define this particular face of intemporality as the intromission of an eternal present, recognisable too in similar expressions of Peruzzi’s: “...the ancients used”, “according to our grandparents...”, etc; for every voice of knowledge, even though it may be distant in time, may be heard as though it were present and active, here and now. In this ahistorical time, there is no separation between past and present, only cohabitation attested by the almost invariable long-lastingness of the actions derived and the objects produced. Knowledge is always conserved by the person who receives and appropriates it, but at the same time it is constantly enriched and renewed, however imperceptibly, in the sacred respect for ancestral customs.

When, with the advent of Humanism, history appeared on the scene of Western culture, men prepared to move away from the past and observe it from afar. The possibility is suggested that human events may be studied by an external observer and even by one who has nothing to do with them. The hegemony of close time is replaced by a distant time in order to offer a new and double perspective: towards the past, by the cognitive power of history, and towards the future, with the predictive efficacy of the project. The impossibility of sharing in the past because of the distance in time that separates us from it is not the only issue, but the conviction that

in order to interpret it properly it is essential not to belong to it. In a way, the modern idea of history seems to repeat a similar course to the one described by science, because the past is observed under the form of a “phenomenon”, a dominion that encapsulates the meaning of the events that have taken place but does not necessarily coincide with them, and as such it must be analysed and explained by reason. This vision presupposes an attitude towards time and a conception of human behaviour and natural phenomena that were unheard of in ancient and medieval cultures. Foucault reminds us of this: “It is true that History existed before the constitution of human sciences, [but it was] a great flat history, uniform in every one of its points as though the tide had dragged in, in the same ebb or flow, in the same cycle, all men and with them all things, animals, every living or inert being, even the calmest faces of the earth.”

Things as such are disappearing, as occurs in the world of science, and are replaced by what they can represent if they are observed through certain interpretation models. The past is not behind the door of our present, it does not communicate with us in a confidential narrative tone, it does not act as a guide for our usual gestures. It is evident that history shall continue telling us a tale, but the point of the story will not be what eye witnesses saw, as it was, for example, for Herodotus, but reality that can be reconstructed by voiceless, eyeless, limbless sources: documents. In any case, this way of narrating, the last residue of a connection with the reality of facts, will lose interest and be replaced by an analysis of what is hidden behind the facts.

“The collective memory and its scientific form, history, are applied to two types of materials: documents and monuments,” Jacques Le Goff tells us, emphasising the supremacy of historic memory over the logic of inherited testimony, that is, the definitive transfiguration of objects into documents. Documents can reveal clearly to us the deeds that took place at the beginning of human actions, the creative tensions and the scenarios that characterise the development, the desires and the thoughts of the artificers, the prescriptions and calculations of constructive solutions. Objects continue to exist as a repertoire of

the past – a simulacrum of life – and even if they have lost their original practical function, they acquire a historical value that goes beyond the value of usefulness. The historical value will also turn its accidental consistency into heritage of memory, into a document.

“History,” Fevre tells us, “is of course constructed with written documents, when there are some. But it can or must be wrought without written documents when there are not any [...]. Therefore, with the word. With signs. With landscapes and tiles. With country forms and herbs. With eclipses of the moon and the reins of draft horses. With geologists’ analyses of stones and chemists’ analyses of metals. In short, with everything belonging to man that depends on man, serves man, expresses man or demonstrates man’s presence, activity, tastes and manners.”

We still have another step to take, perhaps the most radical one, and that step consists in the very extinction of the document, in accepting its loquacious absence: “Take good note,” says Le Goff, “that historical reflection is applied today not only to the absence of documents, but also to the silences of history [...]. It is necessary to draw up an inventory of the archives of silence, and make history on the basis of documents and their absence.”

#### *Tradition / Production*

We have some historical “recipes” for *cocciopesto* mortars, that is, lime mortars containing pieces of brick. In one of them, Vitruvius affirms, “the result will be better still if a third of ground and sieved ceramic is added to the river or sea sand”. In another, Francesco di Giorgio Martini states, “if a third of ground ceramic or old roof tiles is added, it will be much more resistant”. The expression “old roof tiles” is very important: the tiles must be old, as Cesare Cesariano also pointed out in *De Architettura*. In the early years of the 20th century, Rondelet adds that, apart from old ones, “it is worth choosing well-fired tiles”. Old, well-fired tiles, then. These are precepts of some value because they inform us that a constant ingredient of traditional *cocciopesto* is old – never new – ground roof tiles, crockery or bricks. Besides, in order to perform correctly the typical hydraulic (and waterproofing) functions of *cocciopesto*, it is preferable to use well-fired bricks, where there is a

strong presence of silica, aluminium and iron.

On the contrary, the modern production of mixtures for mortars with *cocciopesto* uses ground bricks fired at the right temperature in industrial kilns, attaching little importance to the chemical action of these elements and, above all, ignoring the *grasello* function or the flowers of lime in the compound, a matter about which we unfortunately know only too little. In short, we can affirm that the demands of industrial economy and the euphoria of technological innovations have led us to extract from the general principles of science the homogenous axioms derived from production, giving rise to ulterior motives to disdain tradition.

A specific aspect of that tradition resides in the figure of the builder, the artificer of the fabric. He is a craftsman who is used to working with his hands and with tools, but his art does not only depend on these facts: a craftsman is one whose actions are guided by a large store of theoretical knowledge and a special talent that is a mixture of creativity and secrets of the trade. His way of working is not without unforeseen factors, because no building works, although based on inherited certainties and experience, involve mere mechanical repetition. The preparation of a mortar and the movements necessary to spread a layer of plaster are, at the same time, always the same and always different, like the natural phenomena of sunrise and sunset, the seasons and florescence. The “wisdom” that guides the work and the rite of constantly making similar movements are always present, but each case and its diverse circumstances behave as variables that are difficult to control. In other words, every result of craftsmanship involves the repetition of the execution phases, including the raw material and the way it is handled, but the result constitutes a unique, unrepeatable work. In every hand-made object the steady sameness of the productive cycle goes side by side with uncertainty regarding the result.

When tradition did not supply the necessary knowledge and the master builder had to tackle a new problem such as those facing, for example, the first builders of Gothic churches, he found the task was beyond what his own personal experience could handle. His knowledge

was not based on principles general enough to permit him to control all phenomena. And besides the art of building, this was also true of all trades where materials were handled and treated or of the execution of secondary details or little everyday objects.

Therefore, in the modern age the abstractions of science not only challenge the empiric origin of ideas but give rise to a different way of understanding productive techniques. From now on, scientific culture will more and more have the double task of directing existing techniques and producing new ones. The physicochemical and mechanical properties of materials will be analysed; the laws of equilibrium and static behaviour will be recorded in more and more detailed forms (and formulas); the extraction, preparation and manipulation of matter will be entrusted to mechanical procedures and machines built in turn by other machines. Hand-made procedures are being replaced little by little, albeit relentlessly, by industrial organisation and production methods. The whole system seems to be based on the transfiguration process we have already observed in the behaviour of science and historical research. Furthermore, the requisites for acceptability of industrially produced commodities will be defined according to a “quality standard” that will obey criteria of a quantitative order, of measurements; the production of objects will be expected to comply with features predefined by market requirements, and not far from an also defined and controllable quality level. Industry, substituting consumption for use and the controlled homogeneity of manufactured products for the peculiar singularity of craftsmanship, introduces other reasons for the crisis of tradition.

*How can we answer the questions we posed at the beginning then?* Once we have rejected the mechanical interpretations of an effective recuperation of tradition, we find ourselves face to face with an order of problems that seems to affect the very structure of our knowledge, whose origin resides in the vast, multiform conjunction of Copernican changes that characterise modernity. And yet the way seems clear. An era of effectiveness characterised by works “according to nature” is attained through a new idea of



science and history, the possibility of “hybridising nature”, nourished by a great curiosity about the laws that govern the physical world and human behaviour, until a sort of “oblivion of nature” that involves science and history is reached. From the last century, our interest is moving away towards a form of knowledge whose object is knowledge itself, at the bottom of which lies the reality of natural and human phenomena.

In this typical concern of our times to generate knowledge from knowledge –culture from culture– empirical practices, science and history lose their original disciplinary boundaries and become immersed in the itinerary of nomad thought that is not interested in excluding or prioritising anything in particular. One might object that all of this suffers from a kind of theoretical evasion, incapable of producing action, and that the world demands more action than reflection. But this safe-keeping of knowledge not only involves decisions and technical acts, especially in the ambit of material culture –and therefore in the field of conservation of historical assets– but requires a radical new way of tackling current processes of decision-taking and application of techniques, opening up new perspectives for research.



**Pablo Latorre & Leandro Cámara**  
**ARCHITECTURAL SURVEY FOR**  
**RESTORATION: NO METHOD**  
**WITHOUT TOOLS**

Architectural drawing is the graphic representation of a fiction, a geometry and nonexistent construction, merely imagined by the architect to fill an empty space. Drawing is therefore the architect’s major tool and means of expression, subject only to the subjective mechanisms typical of the creative process, which confers upon it a unique value that makes it a manifestation of the artistic character. During the development of the architect’s work, architectural drawing has different purposes or uses. The sketches architects make at the early stages of their work are more personal, expressive and immediate portrayals without any definite scale, as a means of imagining and designing an architectural project. A more elaborate and

probably more “artistic” or commercial representation of the project is made to show the promoters or future owners the form, configuration and the most outstanding characteristics of the project to convince them that it is viable and apt. Finally the more technical, detailed and precise plans are made to define the construction and serve as a blueprint for the execution of the project.

The construction of the architecture requires the draughtsman to make an effort to submit that fictional geometry to static laws and construction science, and the design to the laws of Euclidean geometry and mathematics. At this moment, the drawing becomes just another tool in the construction process and must be made according to a previously established and accepted graphic and representational code. It is these “technical” representations that permit all the agents involved in the production and construction to understand the architecture and they also constitute a tool to estimate the cost and plan the execution.

Unlike imagined architecture, the form of a historic architecture responds to complex transformation processes, the result of the long periods of time over which they have come about, which endow it with a deformed, altered geometry. The form and the geometry defined in the design of a project changes during its execution because of the errors committed and the deformations it will undergo in the construction process. But, furthermore, it will go on changing over the years according as it interacts with its surroundings and the society that uses it. From the very moment they are used, the materials will begin an erosion and degradation process involving loss of mass and shape that will also affect the cohesion and configuration of the construction elements and the overall stability of the structure, which will continue to suffer deformation. Any alteration of the equilibrium of the setting where it stands and natural disasters or wars can also affect its stability. Finally, the normal functioning of the building will bring about constant transformations in its structure and construction.

As a consequence of this transformation process, in historic architecture we can distinguish between the theoretical form

defined in the project and the actual form it acquires with the passage of time. These two ways of seeing the constructed reality oblige us to ask ourselves what the aim and scope of an elevation should be.

Should we represent the shape, the proportions and the original geometry or, as precisely and in as much detail as possible, the deformed and eroded metrics and geometry of the monument? In fact, should we represent the actual state of the architecture altered by the passage of time or, on the contrary, erase these traces from the representation and draw the theoretical state of the monument, as though we were drawing a project for it?

The discipline of architectonic survey originated during the Renaissance associated to the interest aroused by Roman architecture. However, the real development took place throughout the 18th and 19th centuries, when the study and classification of historic architecture came to the fore. In this period, architectonic surveys had a taxonomic function, as drawing did during the same period for naturalists, who focused their efforts on producing a complete classification of living beings, and used drawing as the fundamental descriptive tool for their scientific work (fig. 2). With a similar aim to the naturalists, architects and art historians also attempted to establish a complete classification of historic architecture that arranged in time and according to typologies all the architecture that was conserved. To make this classification, it was necessary to define the typological characteristics of the different recognised styles, drawing the most important and representative monuments of each of them. Furthermore, the greatest source of inspiration for the study and surveys of historic architecture were 18th century neo-classical architecture and 19th century neo-medievalist styles. During these periods, architecture sought renovation in the great architectures of classical or medieval times, so architects made a point of measuring and drawing them, either in their actual state of ruin or restoring them to their original appearance.

It is essential to mention here, among many others, the names of G. B. Piranesi (1720-1789), F. Mazois (1783-1826), P. M. Letarouilly (1795-1855), L. Canina (1795-1856) (Canina 2000, fig. 3), G.

Valadier (1762-1839), Viollet le Duc (1814-1879) (Midant 2001), A. Choisy (1841-1909), the pensioners of the École des Beaux-Arts in France, etc., not forgetting the work of hundreds of other draughtsmen, illustrators, landscapists and architects who during that time produced countless images and surveys of historic European architecture and, coinciding with periods of colonialist expansion, of the architecture of the great civilisations of Asia and Africa.

It is logical that these efforts to draw known historic architecture provoked debates about the methodology, the objectives and the importance of graphic surveys and that the latter were transformed little by little with the advance and technical development of the measuring tools. In this respect, it is important to mention the polemic aroused at the time by the work of the Frenchman P. Letarouilly, who was accused of inaccuracy and regularising his drawings with an academic spirit, and defended himself by stating that surveying is a critical operation that should represent the image of the building according to the architect's project and not the deformed image of its current appearance.

#### *Teaching architectural drawing and survey*

The drawings that students of Architecture are expected and obliged to produce in project subjects are the same as the ones usually employed in submissions to architectural competitions: very rich in graphic and formal resources. These presentations are judged according to their aesthetics and the visual impact they produce, as well as their capacity to communicate the "idea" that served to generate the project. Unfortunately, these brilliant illustrations of "embryo architectures" with complex forms and geometries more often than not lack the technical rigour that should be expected in a self-respecting school of architecture. Nearly all of us have suffered the disassociation that exists between the subjects of Construction and Structures and Projects, which merely confirms the crisis in the profession –as we understand it today– and its division, like in many European countries, into two specialities: the first, more artistic and commercial and the second more technical. It is as though

the science of construction were not an intrinsic part of architecture and could be detached from it, exclusively serving the symbolic, iconological, formal and economic interests of the promoters.

In this context, it is not difficult to understand why the architectural survey, its methodology and the techniques that we need to know and master to make it are not included in the syllabus of a school of architecture and why the students who study a master's degree lack the necessary training to produce a good survey. The only knowledge they have is limited to the basic use of triangulation with a measuring tape learned in the drawing subjects in the first years of their studies, where the survey is considered the drawing of a built architectural project. Naturally a couple of hours or at the outside one evening dedicated to this subject in a master's degree is hardly sufficient to have an idea of the techniques and methodology of architectural survey and the applications of this work in the field of restoration. Our sensation is that these explanations end up "overwhelming" the student, who feels incapable of putting them into practice and quite unable to assimilate them.

This problem inevitably means that most of the surveys used in the restoration of monuments are mainly "architectonic", and usually limited to representing an idealised orthogonal geometry, with metrics obtained by measuring the accessible points with a measuring tape and in which the bonding and other elements that make up the survey are not represented or at the most are drawn as a mesh. Only recently do students have the opportunity to choose the specialisation of restoration in the second cycle, for instance in the Granada school, with some optional subjects, among which the architectonic survey is a four-month course, with a programme in which the methodology, techniques and tools necessary to make a survey are completely updated.

Unfortunately, the didactic capacity afforded by making surveys of preexisting architecture before starting to draw one's own architectural project has not been given enough credit. The survey is in a way a similar process to the project, whose result is the representation of architecture, either real or imaginary.

However, unlike the work of drawing up a project, a map obliges the person who makes it to experience architecture, to live and study it, to examine and observe all its details and finally measure and represent them, forcing him to relate the reality with his scale drawing throughout the process. It is very important for a student to draw the constructive elements that comprise the architecture of a building and study its configuration, defining its building system and imagining the layout of the materials that form it. The architectonic survey is a reflection about the constructed reality provided by the tools and the capacity to intervene on it or to design and imagine other architectures.

#### METHODOLOGY, TECHNIQUES AND TOOLS FOR GRAPHIC MAPS IN ARCHITECTURE

##### *Analogical survey*

I will never forget how impressed I was the first time I saw the original drawings of the survey of Santa María de Melque made during the archaeological excavations (fig. 4). The archaeologists and their draughtsmen had used the methodology of field drawings of excavations to architectural elevations and superimposed a grid of cables and elastics, generally 1 x 1 m. on the basis of a series of tape measurements referenced on the grid, they drew in pencil –directly in scale 1:25 or 1:20 on millimetre paper – all the details of the elevation of the monument in each of the squares of the grid. Its shape and dimensions had been drawn on the materials that comprised it constructively and been portrayed individually by representing totally the outline of its bonding and each of the renderings, marks, reliefs, cracks, graphites, erosions, fissures, etc. that characterised the geometry of the surface. Colour and grids were used as code to differentiate between elements, types of material, etc., and, besides, the drawings were covered in notes, observations made by the draughtsman or the researcher.

They were not the surveys we were used to seeing, made with a set square after merely measuring with a tape: they were drawn by hand directly from the building, which required very meticulous draughtsmen with great graphic skill and this endowed them with enormous documentary and artistic value. Each

square of the surface of the walls was drawn with the same precision, detail and care as excavations. Their conception and the representation criteria brought the results closer to cartographic work than the usual architectonic elevation, by assimilating the surfaces of the elevations to those of the territory. Following this criterion, the survey was complete, all possible elevations and sections and all the floor layouts were drawn, which made it possible to represent the whole visible surface of the maps of the building. But at the same time they were technical drawings, whose precision was determined by the superposition on the monument's surface of a grid that avoids the accumulation of errors during measurement. With this technique, the draughtsman's precision in the scale representation on squared paper of the surface of each square does not affect the global measurement and is restricted to the square of the grid that is represented. The general precision of the work depends only to the precision of the grid, much easier to obtain and, above all, to guarantee exactitude. The use of a reference system also makes it possible to superpose the common points of this section in each of the planes that comprise the survey, which permits one to relate them metrically in space. However, in spite of the level of detail and precision obtained by means of this system, in practice it was not possible to generalise its use as a method to be included in a restoration project. For its execution, it is necessary to place an elastic grid over the surfaces of the monument to be drawn, which requires scaffolding in order to work in situ, and it also requires a great deal of time. These conditions involve great expense in the auxiliary equipment and a length of time for the preliminary study processes of important monuments that is difficult to justify and impossible to fund with the usual budgets for an architectural survey, unless they are associated with the development of the restoration works. In fact, this methodology has hardly ever been applied to a restoration survey and has usually been associated with the excavation of small monuments and churches with great historic and archaeological value. As we mentioned above, it was archaeologists who, when

they realised there was physical and temporal continuity between the remains excavated and the emerging ones, decided to document the monument with the same methodology they used to document the profiles and elevations of the ruins discovered. Besides, the same teams that drew the excavations made these surveys during the excavation campaigns. However, such a rich experience could not have been more frustrating, because it made us understand both the need to work with precise, detailed plans and, at the same time, the pointlessness of tackling the map even of a small Romanesque church without the proper tools and methodology. We realised it was impossible to produce a high quality map with the mere aid of a measuring tape, since it is impossible to control the errors accumulated from one measuring to another. Besides, the problems of measuring the high parts, the overhang of the vertical elements, the deformation of arches and vaults and the drawing of the bonding are simply insoluble. At the present time, the generalised use of laser distance measuring tools and the ease with which digital photographs can provide metric corrections help solve the problem of measuring high parts and drawing bonds. However, it is necessary to point out that these tools cannot guarantee the absolute exactness of the measuring, since they do not define a precision reference system for all the work, which can only be established by topographic means.

#### *Analytical mapping*

In this process of perfecting the techniques available to make a map it is inevitable to tackle topographic work for the first time, essential to understand photogrammetry. Topography permits the definition of the coordinates of points in space, based on trigonometric calculations of measurements of angles and distances obtained from reference stations. The introduction of topographic techniques in the survey process is, without a doubt, the most difficult "methodological leap" to take from the field of architecture, as it obliges us to superpose an analytical reference system on traditional measuring and analogical representation and introduce angle measurements in the data collection process. At the end of the day,

topography obliges us to abandon classical Euclidian geometry – whose usual work method is drawing – for an analytical geometry based on numbers and mathematics.

It is this mathematical condition of topography that permits the introduction of values of precision and error in the survey by establishing a reference grid of a closed polygonal structure, with defined and controlled error. Topography is evidently not a drawing tool and its objective is limited to locating a series of important points of the architecture of the building, in which the rest of the survey will be placed, with quantifiable precision. This incapacity of topography for drawing means that photogrammetry is an indispensable and complementary technique in the work of analytical survey. Photogrammetry is a measuring system that permits one to obtain the situation and dimensions of an object in space on the basis of two or more conical projections of it. Photogrammetry is based on the same principles as topographic systems, developing an inverse process to perspective. Its basis is known parallel to perspective, but its development and extensive application as a measuring and representation technique was not produced until the advent of photography, by replacing perspective with photographic images.

In the early photogrammetric equipment, with high precision optical and mechanical technology, the analytical and three-dimensional capacity was completely limited by its recording system, which had necessarily to be done by means of an analogical representation on paper. Besides, its technology made it extremely expensive, so it could only be used in restoration by certain institutions. It was computerisation of photogrammetry and the possibility of recording on CAD programmes that permitted all the analytical and three-dimensional capacity of photogrammetric theory to be conserved, which brought the price of this equipment down considerably. However, it was the possibility of recording photogrammetric information on CAD programmes that permitted the analytical information obtained from topography and photogrammetry – without losing any of its three-dimensional power – to be converted into two-dimensional graphic

images on the screen, which can then be drawn on paper. Stereoscopic photogrammetry restitution equipment uses the principles of stereoscope and photogrammetry simultaneously to permit the operator to draw continuously in three dimensions from a three-dimensional optical illusion of the object that he can trace. In fact these apparatus function as an actual digitalising pad in three dimensions, in which the operator draws on the CAD programme, tracing the virtual three-dimensional image directly. This system makes it necessary to make always a drawing with continuous polygonal lines (3Dpoly) in which there are no pure curves, which involves serious graphic limitations in comparison to an ordinary hand drawing. At this point, it is inevitable to emphasise the often anonymous work of the photogrammetry operators, whose manual skill is crucial for the final graphic result of the photogrammetric works (fig. 5).

#### *The three-dimensional photogrammetric model*

We learnt the photogrammetric technique, its work methodology and equipment praxis during our collaboration with Antonio Almagro on the restoration of the church Santa Lucía del Trampal in Cáceres. The results of analytical photogrammetry, which Almagro applied for the first time on this little church, permitted him to place the result of all the restitution of each elevation in a single drawing archive. By using a unique system of coordinates in the topographic work, each of the restored elevations was placed in its exact place in the CAD space, constructing a three-dimensional and analytical model of the building which he used to make perspectives of the restoration proposal (fig. 6).

The result obtained was surprising, since it made it possible to introduce in the computer a database of coordinates (x, y, z) of thousands of points of the building in 3D lines in the CAD space, representing the arrises of their geometry or the decoration and outlines of the materials, cracks, erosion, etc. The concept of scale disappeared from the model because in the “infinite” analytical CAD space the representation of architecture could be performed with total precision and in as much detail as could be introduced. The

really innovating side of these models is that they constitute an analytical model of reality in which metric consultations with a numerical value may be made directly on the graphic image on the screen. Besides, we can obtain multiple views of this model in any of the known systems on the CAD, which permits us to make both traditional elevation drawings in the dihedral system and multiple axonometric and conical perspectives from any viewpoint. Nevertheless, several problems that must be solved arise in the work and manipulation of these wire models since they are made on the basis of 3D lines. The size in terms of computer memory makes them unmanageable, and especially so ten years ago, which makes it necessary to break them up into many archives to be able to handle them. Furthermore, these line models are completely transparent, which, in the complete perspectives of the model, turns them into an incomprehensible tangle of lines crossing each other in space so that handling them is a very complex matter. These problems, together with the tradition of presenting the maps in 2D elevations, floor plans and sections, often caused the models to become a curiosity or subproduct of the photogrammetric work that continued to produce spectacular elevations of the monuments. In spite of these difficulties, we did not want to give up the possibilities these three-dimensional wire models could have as a metric database for restoration and, for that reason, we focused our research in the field of photogrammetry in obtaining, manipulating and exploiting them (fig. 1). To this end, we decided to achieve the surveys by a massive production of photogrammetry, which usually covers the whole visible surface of the monument, which multiplies and complicates data collection and requires the use of auxiliary mapping tools. To solve the handling and visualisation problems, we separated the models converted into drawing archives according to constructive elements, breaking each one up into layers according to geographic orientation values and the types of line. To make this work easier, we designed a series of computer routines that permit the draughtsmen to place each line they draw on the layer and in the relevant archive or

correct this designation when they detect an error. We had to develop graphic and alphanumeric managers to locate and manipulate all the archives and layers created in the break-up of the monument so that they would allow us to locate and select the ones that were visible in a specific elevation or perspective. We also developed concrete orders to be able to replace the profiles of cuts of the model with a predefined plan and execute the generation of surfaces on the basis of the outlines and profiles rescued. Finally we developed specific projection orders that would allow us to extract concrete 2D views from the 3D model on a concrete predefined plan, necessary so as to draw the results of the research or restoration project (fig. 7 & 8).

#### *Architectural survey: a difficult equilibrium between the analogical and analytical systems*

The barrier between the two survey methodologies (analytical and analogical) is probably the greatest stumbling block in practice. It is as difficult for architects to understand they must obtain the coordinates (x, y, z) of the most significant points of the building related to a single system of Cartesian axes as for topographers to decide what are the points – among the thousands of possible ones – that define the geometry of a building. Besides, there is a scholastic and instrumental barrier that requires architects to learn the trigonometric principles of topography and photogrammetry and the use of the apparatus necessary (theodolites, etc.) and topographers to study and understand architecture and its representation. It is topography and photogrammetry that give the surveys precision; but only the drawing, its practice and common use make it possible to make correct detailed representations of architecture and archaeology. We have had occasion to verify how teams of topographers specialised in making architectural and archaeological surveys underestimate the value of drawing and try to avoid it, attempting to replace it with other types of representation or by exploring “automatic” restoring and drawing systems. Neither a succession of photoplans nor 3D laser scans can reproduce the process of graphic selection and analysis that a specialised



architectural draughtsman can. Evidently, it is not our intention to minimise the importance and the applications of these techniques that have recently invaded the world of graphic survey, but we are convinced that nothing can take the place of drawing as a tool for documenting and representing architecture.

A photoplan is obtained from one or several digital photographs of a surface that have been metrically rectified by correcting the optical deformations and united in a single scale. The resulting image of the composition constitutes a photographic plan that has acceptable metric values and can replace the drawing of the surfaces of the architecture, with the ensuing saving of replacement time. As opposed to the synthesis involved in the line drawing of photogrammetry, these images incorporate important values like texture, colour and shadows into the map, facilitating the recognition of forms, materials and also all sorts of pathologies (erosions, chinks, cracks, vegetation, etc.). Today this type of documentation is used abundantly by restoration and archaeological teams, who focus their work on the study of the surfaces of architecture. However, a succession of these photographic images cannot replace the drawn representation of an architecture, since they can only reflect the texture of the surfaces, neglecting such essential three-dimensional aspects as spatial, formal, functional, constructive, etc. and must be complemented with the representation of the outlines and forms of the architecture. On the other hand, these documents are “pixelated” images, that is, they are not vectorial or analytical, which is a disadvantage in field work and, above all, in the drawing of the restoration project. It is at this part of the methodological process of a restoration work that these images are clearly insufficient, because it is practically impossible to make the drawings for the restoration project with them; this obliges us to trace the drawing of the architecture from the photographs, thus losing precision and the metric capacities of the three-dimensional photogrammetric model and, above all, obliging us to make a bad restitution.

The cluster of points of a building obtained by means of a 3D laser scanner is enormous and very precise but,

unfortunately, does not represent anything, because the points obtained cannot be identified or associated with those on the building. An oriented, non restituted photogrammetric pair also constitutes an even denser mass of points than can be obtained of the object in the space of a 3D scanned image. In fact these points only have meaning if we are capable of selecting and naming them – specifically recognising their location on the monument – by joining them to other nearby points by means of lines or surfaces that can be identified with the arrises, outlines and forms of the architecture represented.

A 3D laser scan of an architecture – as a set or oriented photogrammetric pairs – requires handling and restitution afterwards to extract the measurements and the geometry representing the architecture being surveyed. In the case of photogrammetry, this examination is purely visual and analogical, since the task of selecting the most representative points of the building is performed by the operator by tracing them from the virtual model. To make the selection of the points obtained from the 3D laser that represent the geometry of the building, a series of metric and analytical conditions that make it possible to distinguish the ones that comply with certain geometric characteristics must be applied. One of the great advantages of this technique is its capacity to obtain easily the geometric grid of complex surfaces, which has numerous industrial applications. In restoration this technique is being successfully used to define with precision the surfaces of vaults and obtain the reproduction of sculptures without moulds.

On the other hand, we have also observed that in the field of architecture the effort involved in making accurate and detailed surveys is often underestimated, as they are classified as unnecessary for typological and aesthetic reasons that echo over and over again the polemic we mentioned in the foreword. We have recently heard a professor of the History of Architecture question the need to draw up a map like the ones we were doing “if the builders of that monument probably designed it with little more than a rope and a very rudimentary measuring system”. Unfortunately, this argument is

constantly repeated to justify the idealised surveys of the constructed reality usually employed in restoration works.

However, this statement permits us to introduce into the discourse the problem that poses the error provoked in the measurements of a survey and the levels of precision necessary to develop restoration works. For example, although we know the design of a round arch will never be semicircular, since the keystone will have sunk in the process of settlement and the supports will have separated, we tend to ignore this deformation because it is not very important when considered in the general measurements of the arch and, above all, with respect to the error introduced in a measurement with a tape measure. Furthermore, when evaluating this error the real difficulty in obtaining the diameter at the springing point of the impost, without the support of auxiliary means must be taken into account, above all if the arch springs from pillars or pilasters crowned with capitals. On the other hand, if what we intend to achieve with the survey is deduce the measurement used by the architect to design the arch, we must take it into account that this measurement is actually altered by the error introduced during its design and construction.

In fact, it is the sum of these errors that accumulate in the surveying process that makes many architects and researchers underestimate precision as a useless effort and draw this arch as a perfect semicircle with its diameter obtained by merely measuring with a tape. It is logical, therefore, that in the process of surveying a document the forms represented should be the geometrised, given the technical impossibility of drawing its deformed geometry with precision with the sole aid of a measuring tape. We must not be surprised to find proposals of proportion design, comparative metric studies of its building stages or models of finite elements, etc., deduced from schematic maps of reality.

Unfortunately, it is this methodological barrier between analogical and analytical systems that prevents one from obtaining high-quality maps and requires professionals to make “a more complex effort”. At the present time it is inevitable to use and combine both systems when making a survey, selecting in each case the



most suitable measuring, recording and representation techniques and tools. Topography endows the survey with controlled precision, adjusting all the surveying work in the analytical space. Photogrammetry permits the representation of all the “geography” of the surfaces of the monument in 3D, with all the necessary detail and with a high level of precision, but the geometry of the profiles of the architecture is very often inaccurate because of the limitations caused by the degradation of reality and the photographic model used. It is not possible, either with topography or photogrammetry, to draw the section of carpentry fittings, the design and geometry of the profile of a deteriorated mould, etc., which would require a task of interpretation and synthesis of reality that would have to be performed on the monument itself by using the more traditional tools of analogical mapping.

#### PRECISION AND DETAIL IN GRAPHIC SURVEY

Before the advent of information sciences and CAD programmes, drawing was the only way of recording the measurements of a survey. The measurements obtained from the monument were reflected in the scale drawing from which they could later be taken by measuring with an architect’s scale. In this way, the precision with which a concrete measurement had been obtained depended on the precision of its representation, which in turn depended on the scale of the plan. An alternative recourse was to record this measurement by means of writing it on the plan, but a massive use of this method marred the clarity of the representation. The scale used for a drawing also limited the amount of detail: the larger the scale the better the richer and more formally complex elements could be represented.

Today recording and drawing in CAD systems has done away with the concept of scale in the task of surveying. The analytical and “infinite” space of CAD enables the representation of architecture with the greatest level of precision and detail we are capable of introducing into information science. Besides, drawing becomes a numeric database that can be consulted graphically. In this context, the values of precision and detail are independent from each other, for they lose

their relation with the scale of representation. With a simple measurement by tape measure, it is possible to make a survey of a monument with great graphic detail, but without great precision. On the contrary, we can obtain the coordinates of the points at the ends of an aris with great precision, but its representation – with this information alone – will lack detail because we will suppose it is straight.

The precision of the measurements made in a survey and the level of detail achieved in the representation define its quality and determine the methodology and tools required to obtain them. It seems logical, when about to make the survey of a monument, that the level of detail and precision be established according to their usefulness. Almagro defines three levels, which he dubs:

- Examination, photographs and sketches with no scale but well proportioned;
- Preliminary documentation, general plans with errors of less than 10 cm and details with errors between 3 & 5 cm;
- Detail documentation, general plans with errors between 3 & 5 cm and details with errors between 3 & 1 cm.

Almagro relates these levels with the methodology, techniques and equipment that can produce them and that we can summarise with his own expression that surveys can be made with footsteps, with measuring tape and by using topography and photogrammetry. Sainz also establishes three levels of precision and detail that he classifies as:

- Rough or approximate, hand drawn with no instruments;
- Habitual, with effective measurements where the monument is accessible;
- Scientific, with the aid of equipment and specialised personnel.

#### *Precision levels*

The absolute precision with which the representation coordinates of a point are obtained is established according to the actual deviation, regarding an origin of coordinates (0,0,0) previously established, of its position. In analogical measuring, only rough precision can be achieved, since there is no error control introduced in the measurement, above all if the measurements obtained are not inserted in a reference grid or polygonal of controlled precision. The control of the error

introduced in the measurement is only possible if the reference system of the measurement has an analytical basis that guarantees the levels of precision achieved. In surveying, analogical measurement can only be introduced inserted among a series of coordinate points analytically obtained with absolute precision. The relative precision of the points obtained from a second origin of coordinates is established by adding to the precision with which they have been obtained the absolute precision with which their origin has been obtained.

In order to guarantee the precision of a survey, it is necessary to have the sketches and notebooks of the planning and development of the field work, the lists of measurements and coordinates of all the points in the reference system and the justification of the absolute precision with which they have been obtained that must always be subject to verification. In general terms, three levels of precision can be established in the survey, associated with a specific drawing scale that will enable us to relate the precision with a coherent level of detail.

\* 1st level: precision <5-10 cm, scales 1:1000, 500 and even 1:200;

\* 2nd level: precision <3-5 cm, scales 1:1000 and 1/5;

\* 3rd level: precision <1-3 cm, scales 1:25, 1:20 and even 1:10.

Before setting about the task of surveying, it is necessary to evaluate the exponential cost associated with precision that must always be adapted to the aim of the work, avoiding unnecessary useless precisions.

In any case, in a survey that is going to be used to develop the execution project of a restoration work, at least the second level of precision defined must be guaranteed in the whole map. It is difficult to study a monument or design with precision the constructive details of a restoration project on a drawing of a structure that is not drawn with the same level of precision and detail as will be required for the new design. But above all, to evaluate the need to guarantee precision in surveying, it is crucial to understand the applications that can be extracted for its constructive and structural analysis.

In studying fabric structures we must bear it in mind that the problem of their equilibrium is fundamentally a problem of geometry: the arrangement of masses in

space determines the stability of the construction. In fabrics it is not possible to rely on the resistance of the materials for stability, because we know: first, that they do not have the capacity to resist tensile stress and consequently flexions and second, because even when working under compression, the importance these stresses can have must always be very limited so as not to cause local damage to the material that could eventually affect the global equilibrium.

This geometric condition could be expressed in the following way: an arch or a vault collapses when it “fits” inside its piers. The inevitable evolution of the materials of a fabric in time is progressive deformation in the direction of the thrusts it bears. When we speak about the action of time on monuments, we are not evoking a poetic figure but refer to a succession of physical and chemical phenomena provoked by the alternation of hygrothermal changes and the interaction of the materials with their immediate surroundings. That is when we say time damages constructions and brings about their inevitable ruin and disappearance. Before deciding what our intervention will consist in, we need to know at what moment of this process we are, how near or far from the final state of ruin and what possibilities we have to avoid it. We will find a construction which in the time elapsed since it was built has adopted a form, similar to the ideal with which it was conceived, but affected by posterior repairs, restorations, demolitions and partial reconstructions, etc. Representing and studying this time-altered form will enable us to deduce the causes that have provoked it. For example, the alteration of the design of an arch will be different if there has been subsidence in the ground or earthquakes or partial ruin; the different quality of the building materials in the different parts of the building or the different exposure to the sun and damp will also influence this evolution. In time, the arch will hold in its deformed shape the memory of all these processes for us to interpret

Our experience in surveying confirms that the deformation of a structure is hardly ever symmetrical, since the conditions of the props are always different. In the case of arches and vaults, an asymmetrical movement of the piers brings about

irregular deformation of its directrix, which adopts the form of the profile of an orange or a potato. Evidently this geometry can only be interpreted if we start with a faithful transcription of its state without adding or taking away any of what is there. Only the correct interpretation of its deformed geometry will allow us to formulate a correct hypothesis of its original design and how it became deformed, affected by the movement of its piers over time. We need an exact representation of the shape of the arch as it is at the present time, the arch and everything around it: its piers and its loads, the materials they are made of and their state of repair. Any evaluation of its state based on incomplete or inexact data will be erroneous and ineffectual and will probably make us perform unnecessary works that would damage the construction (fig. 9).

The representation must include a complete drawing of the structure, with ranks of precision in the geometric definition of all its elements that permit one to appreciate its overhang, bending and curvature in the three dimensions of the space. If we lose any of these three dimensions, we will have ignored a great deal of the problem, for buildings are bodies in space, do not exist on a plan, which is only useful to make an approximate conventional representation both of what exists – the survey – and of what will exist – the project.

It is not possible to establish what precision is necessary for the survey: obtaining the shape of the arch with measurements obtained with a high-precision total laser station can attach importance to obviously accidental events from the point of view of structural equilibrium, such as the erosion of its arrises or small cracks in the material – which will be important at another moment of the analysis – while it may leave other more important issues unanswered, such as the thickness of the materials or the geometry of the elements that lean on or support the arch.

In any case, we could establish two levels of precision in the concrete drawing, one for the geometric shape of the built masses and another for their thicknesses. Whereas the former can be situated between five and eight centimetres maximum error, the latter should be no more than two or three

centimetres. The explanation is simple: the bays of most arches in historic buildings are between six and fifteen metres. There are larger ones, obviously, but not very many and, in any case, as we shall see, the argument is even more applicable to them. With these dimensions, the error established is less than 1%. On the other hand, the thicknesses of the building elements are usually between twenty-five centimetres and a metre and a half, so the errors marked could be up to 10%, which would have great influence on the calculation of masses and thrusts. However, the most important thing in global surveying will be the relationship between the different elements. The greatest problem about conventional analogical surveying, by directly measuring the constructive elements and their dimensions, does not reside in the error that can be committed while taking these measurements but in the relationship between them, in the great difficulty, not to say impossibility, of managing with these means to situate the floor plan of a certain level exactly where it should be in relation with the others, or to make sure the heights measured in different sections refer to the same origins.

It is fundamental to guarantee the exact correspondence between the different parts of the building for the constructive and structural analysis must establish not only the magnitude of the loads or the load-bearing capacity of the elements – the problem of thicknesses – but, above all, how the loads and thrusts are distributed and transmitted until they reach the ground. Only methods of indirect, analytical measuring permit one to establish these relationships correctly: the topographic reference to a single origin of the three coordinates of the whole three-dimensional model of the building and the drawing of each element in its position in space by the use of CAD permit one to establish these relationships.

To sum up, the precision of the survey should aim at fulfilling three aims: to obtain a precise geometric representation of the shape of each constructive element with its displacements and deformations; to determine correctly the thickness of all these elements in order to evaluate their masses; and to find the exact three-dimensional relationship between them all. After this, the survey will address other

aspects, important too in evaluating the safety and perdurability of the building, but more connected with the thoroughness of the detail than its precision: the representation of structural lesions, cracks in the fabric and fissures in the material, which inevitably accompany general deformations and are therefore just as important in this evaluation. The survey must, above all, try to represent with painstaking exactitude all the lesions present and make sure they appear in the right place in the model, but without exacting an exhaustive control of their dimensional precision.

Until now and in general, the studies carried out on fabric constructions have been based on idealised geometries, ignored the reality of the deformation present and used unsuitable analysis tools, such as the finite element method.

Whichever the right calculation method, what must be accepted is that the building is the best witness of its own history and the constructive events that have configured it. Any structural analysis must attempt to explain the real state of deformation and fissures without expecting the calculation of the structure to be more reliable than the structure of the building itself. The result of the calculation must always be compared with the current reality and will be useless otherwise. This comparison will only be possible if we have a precise and faithful representation of that reality. Drawing, as we present it in our work, becomes the essential tool for the analysis of the current and future stability of the fabric structures, although it is not enough on its own.

*Levels of detail and representation criteria.* To achieve total knowledge of a building it is necessary to have a map with a level of detail that permits one to recognise, locate and individualise on the plan any element of the building being examined. What good does it do us to characterise the typology of all the materials in a monument and the pathologies that exist in it or determine the construction phases if we cannot specifically assign the type, pathology or moment of inserting each of the materials that form it?

How can a geologist, a restorer, a historian or any of the specialists that take part in

the preliminary research of a restoration project study a concrete problem if in the development of the field work they cannot point out on the map the observations they deduce from the real building or the exact piece from which they have taken a sample?

In a survey for restoration it is necessary to individualise by means of a drawn outline all the elements that make up the monument. Any material, fissure, erosion, breakage, pathology, etc. that is not drawn cannot be located or specifically referred to later by assigning it a certain characteristic. There must be a graphic presence that allows us to recognise by shape each of the elements that constitute a monument, establishing a direct relationship between the shape of the object and the outline of its representation and from the topological context in which it is located - in a specific position and surrounded by other specific shapes - both in the space of the building and the analytical space of the 3D model or its projection on a plan.

To achieve an adequate level of detail and “normalise” in our work the representation we make in architecture, we have made the following classification of outlines of a monument that can be drawn and that permit their proper representation:

- The arrises that define changes of plane and make up the main geometry of the architectonic object or the site.
- The arrises of the geometry of the decoration of all the elements of special artistic value or typological importance. It is often difficult when drawing to distinguish between these two types of line because the lines of decoration (which also form arrises) are an intrinsic part of the architectonic structure. The graphic complexity a drawing of some of these elements - especially decorative elements - can possess can oblige us to separate them into layers of drawing, or at least two layers, in order to draw them on paper in different scales.
- The joints of the constructive bonds that do not involve a change of plane. The joints between materials are usually represented with a plain line, but we prefer to individualise each of the material that form the building with closed outlines.
- Visible and recognisable breakages and fissures on the surfaces represented.
- Outlines of degradation, erosion or alteration of the materials.

- Outlines of materials and other extraneous elements or organisms that adhere to the surface and alter it physically or visually (vegetation and plants, excrements and animal remains, curves or damp or wet patches, crusts, oxidation, etc.).

- Section profiles that mark the segment or separation between the solid elements of the construction and the architectural spaces.

- The colour or texture of the materials can also be represented by using grids that are also used to mark specific features of certain elements or areas of the surfaces of the architecture that present a certain condition or alteration.

This classification can vary in each survey depending on the characteristics of the monument and the objective of the representation (Almagro 2005: 37).

Furthermore, the classification of the types of lines in a drawing permits us to separate them into layers on the CAD and activate them independently to define different levels of detail, depending on the scale used in the representation.

\* 1st level - arrises and profiles, 1:1000, 1:500, 1:200

\* 2nd level - arrises, joints, 1st level decoration and profiles, 1:100, 1:50

\* 3rd level - all the lines in full detail, 1:25, 1:20, 1:10

Methodologically speaking, it is essential at the study and research stage to have a survey with a level of detail that permits one - by means of a graphic code of grids and colours - to assign each element of the characteristics studied one at a time. For example, when making a lithological survey of the stone in a fabric building, it is necessary to define the specific lithology of each piece by assigning a colour and it is also necessary to define the extension of certain pathologies on the surfaces of the walls, to establish in the archaeological reading the specific materials that make up each one of the construction phases, to define the position and size of the fissures, etc. Detail in surveying also allows us to place on the representation of a concrete piece the symbol that identifies the exact position from which a sample is taken, where a test is performed or a measuring instrument is placed. In the field work it is the analogy established between the reality and its representation that permits us to identify quickly each element or material in the building and draw a symbol on it or

mark it with a grid or a colour that we associate with a certain characteristic. We use the term “thematic cartographies” for the surveying plans that represent the results of a concrete study of the monument. From a detailed graphic survey you can obtain the following thematic cartographies, among others:

- Materials, identification and arrangement of the different types that exist in each group (stone, ceramic, timber, metal, mortars, etc.) and the location of the samples and probes extracted for classification.
- Constructive elements (including the soil) with the definition of the typologies of fabrics and bonds, timber structures, claddings, fittings, stratigraphy of the soil, etc. and of the outlines in ground plans and elevations, location of probes (including the geotechnical study) and endoscopic inspections, results and definition of constructive sections.
- Archaeological chart of the monument and the subsoil, with the definition of the stratigraphic units, interface lines and construction phases and their chronological order (fig. 10).
- Rain damp, location of leaks and breakages in the drainage system.
- Rising damp in the materials and definition of the different seasonal outlines.
- Salts with the definition of the different seasonal outlines.
- Biological chart with the identification, classification and areas affected by active species.
- Temperature and relative humidity of the air in the different spaces of the building with gradient curves of the different seasonal outlines.
- Pathologies and alterations of the materials, identification and arrangement of the existing pathologies and location of the samples taken for classification.
- Deformations of the structure and interpretation of the historic movements, on the basis of a supposed initial geometry.
- Active movements detected in the structure and location of the different measurement apparatus used and the results obtained.
- Cracks and fissures present in the fabric, evaluation and relationship between them and with the levels of deformation and movements defined.
- Structural lesions of the different bodies of the fabric with evaluation of loads and

determination of thrust lines.

- Inventory of the most important artistic and typological elements of the architecture and the existing movable property and their location in the building.
- Surfaces, uses and circulations, chart of the surfaces with the layout and designation of the uses of spaces and existing circulations.
- Installations and existing input, layout and output networks of: plumbing, sanitation, electricity and lighting, heating, ventilation, fireproofing, safety, telecommunications, etc.

In our surveying work, whenever it is possible, we draw the complete outline of each material or element separately – with a specific contour – and avoid reducing the representation of the joint to a mere line. This way of representing the bonds allows us to associate a specific, differentiated graphic entity to each material or element in the building in the CAD drawing and later relate it to a certain characteristic from an alphanumeric database associated to the element sought. In computer work, that relationship between graphic entities and numeric or written values from a database constitutes what is known as a cartographic information system, which, in this case, will be specific for the monument. This monument information system (MIS) can be consulted both in the plan with response in the database and on the contrary, obtaining cartographies of specific themes automatically by means of consultation.

According to this data collection process and that of defining the characteristics and pathologies of the building are completed, the surveys will fill up with colours, grids, signs, texts, etc., and the database related to these codes will be completed with the information gleaned from the different studies. In this way, the research will convert the surfaces of the building (by means of the plans) in a series of topologically related facts.

One of the main aims of mapping is precisely its capacity to permit us to relate reality to the data extracted from the studies carried out by superposing them, by means of the data taken from the different thematic cartographies, on a concrete part of the monument. It is precisely the relations we can establish between the different features and

pathologies defined that permit us to draw conclusions and make a justified diagnosis about their origin, thus planning the suitable restoration solutions transversally. Finally, the level of detail of a survey will allow us, at the project stage, to delimit the scope of the treatments proposed for restoration, which can be individualised for each of the material represented. Besides, the solutions of the project, at execution level, can be drawn on the survey with the same level of detail and precision with which the project has been drawn up, in the conviction that its metrics will be correct and its formal and constructive impact can be evaluated confidently evaluated before putting it into practice (fig. 11).

#### SURVEY FOR RESTORATION: THE REPRESENTATION OF TIME

Although some of the best restoration specialists seem to believe that the survey of historic architecture, necessary for restoration works, must be a precise and faithful reflection of its constructed reality, most architectural surveys are still made by drawing only the geometry of the arrises and an idealised simplification of the decorative elements. Very occasionally, the bonding methods are drawn or the representation is simplified by means of a grid. When a monument's geometry is deformed, altered or broken, these irregularities are usually corrected by drawing them as they should be, removing the signs of degradation, the alterations, cracks, fissures, etc. that disfigure the “original” form of the architecture.

When appraising the reasons why most architectural surveys still follow these parameters, it is necessary to understand that the professionals who make them, usually architects, are conditioned by the conceptual and methodological tools of their trade and do not know enough about the techniques and equipment necessary to obtain a precise survey. In the first place, there is a tradition for drawing and making projects that makes the architects repeat the process they usually develop in their work, transferring by analogy – directly on to the plan – the images of their architectural thinking that they now replace with the idealised image of the monument they have before them. Without realising it, architects tend to



idealise the geometry of the architecture they imagine when they observe the reality, giving form to what is deformed. They usually draw a straight arch and a semicircular round arch, because that is the shape with which they were conceived and built and the way they would draw them in a hypothetic project for a building that is to be erected. With this attitude, all the analytical technology to record the reality metrically with precision is quite useless and bothersome, since its use and the data obtained prevent a proper formalisation of the monument. Thus architects justify their surveying work after an operation of analogical restitution of the constructed reality that they adapt to their usual work tools and the simplest measuring technique (with measuring tape), which is the only way they know and are capable of using, easy to use and cheap.

Following this methodology, the best survey, by means of drawing, ends up being an authentic architectonic “restitution”, by means of a meticulous study of forms and the composition of the architecture being built. Going back to the anecdote we mentioned in the foreword, it is easy to understand why, from a more academic point of view, the graphic results of photogrammetric works have been criticised, precisely because in their efforts for representing reality, restitutions are often incapable of making the architectural shape of deteriorated or eroded elements intelligible so that they can be misshapen. The use of topography and especially terrestrial photogrammetry as surveying techniques since the late nineteenth century has permitted the appearance of some very detailed and precise representations of architecture that contrasted with the more academic representations. Since then, architectonic photogrammetry has gained ground as a discipline in the different state restoration services, the only ones that could afford to buy this expensive equipment and maintain specialised staff to make the surveys of their more important monuments. However, research into this discipline focuses mainly on the development of photogrammetric techniques, in continual transformation, in the problems involved in representing architecture by means of restitution and in its application as a technique for

documenting architecture, as we can see in the successive publications of congresses organised by CIPA (International Committee for Architectural Photogrammetry).

It was mostly in Italy, in the field of archaeology applied to architectural research and in the practice of monument restoration, especially when archaeology was linked to the work, that they broke away methodologically from the usual academic treatment of architectural elevations and they started to do this work deliberately seeking precision and exactitude and using it as a fundamental tool in the research carried out before restoration.

The archaeological methodology applied to architecture requires every joint, parge coat, fissure or chip on the surfaces of the building to be reflected in the representation. The archaeologist’s method is based on painstaking, detailed, descriptive observation of reality, which must be absolutely faithfully documented, which means the draughtsmen and researchers must be extremely observant and very meticulous in their representation. In fact, excavating is knowing and documenting the reality discovered little by little during the digging, interpreting it before making it disappear to uncover a new layer and a new context.

But it is not only reality that provides the keys to research a monument but, above all, the order this reality appears in. It is the relationships established between the different elements that form it that make it possible to interpret it. It is not enough to study and describe what appears, but it is essential to understand how it appears and why it appears with a certain configuration. Because the whys and the wherefores of the conserved structure respond directly to the unique, specific temporal process of the building that has determined its construction and degradation over a period of time.

The preliminary study phase before the restoration of a monument must be based on the understanding of the simultaneity of the synchronic and diachronic conditions of the historic architecture. The synchronic condition will oblige us to study the architecture of the monument as it stands, with specific formal, constructive and functional characteristics

and concrete pathologies; and the diachronic condition will oblige us to understand that its structure is the result of a complex process of transformation in time that explains its history. It is this double condition that obliges us to understand historic architecture: first, as matter and structure, with a determined configuration and concrete pathologies that we inevitably need to modify in order to correct its deficiencies and prevent its destruction; second, as a historic document that must be conserved as it is in order to transmit all the information inherent in the relationships that history has gradually established between its elements.

In the recent Architectonic Survey Charter approved in Italy in 1999 and in Spain in 2000, the survey concept is understood in the broadest sense as the complete documentation and study of the monument. In the first paragraph of the foreword, the Charter determines as a prior requisite for any intervention on cultural heritage, complete knowledge of it, understood as a complex research task to reconstruct the processes that have configured it over the years.

The different forms of alteration and erosion of the materials, the deformations in its geometry and the fissures, cracks and breakages in the structure are nothing but the monument’s response to the action it has been submitted to the physical and human milieu in which it stands. The response may be immediate, provoked by the weight of the building, by a sudden alteration of the surroundings, new building or a traumatic external event (war, earthquake, etc.) and manifest itself by means of fissures or cracks accompanied by instant subsidence or deformation or can be the result of continual degradation and erosion of the matter and slow deformation of its structure caused by the action of the environment.

It is precisely these alterations of the “ideal” form and geometry of the monument, signs and warnings of its historic or current pathologies that provide the keys to understand and quantify them and decide how serious they are at the present time. Only by studying, measuring and interpreting them can their causes be deduced and the origin be diagnosed to plan the works that will correct them,

make their effects disappear and permit the structure to respond more adequately in the future. Only a rigorous representation of the reality that contains in the drawing all the details that time has brought about on the building will allow us to study, arrange and understand the whole constructive process the building has undergone and how it has responded to the environment where it stands throughout its history.

The need to draw with precision and exactness the deformations, erosions, fissures and all sorts of alterations must be seen in this context, however fragile and constructively poor they may seem to us, and they must be adjusted as closely as possible to reality before the restoration works alter them. As a tool for restoration it is methodologically useless to obtain the representation of architecture that some would write with a capital letter; the necessary tool is the representation of the “historic” architecture as it really is, affected by the alterations caused by its own history over the years.



Mariana Esponda Cascajares

### **ARCHAEOLOGICAL ZONES IN ITALY AND GREECE RESTORED WITH REINFORCED CONCRETE. ASSESSMENT OF THEIR CURRENT STATE**

At the beginning of the 20th century, great changes came about in the structural conception of historic buildings and this had a fundamental effect on the sort of interventions carried out on them. The practice came into being of replacing traditional materials with a new material, reinforced concrete, which was attributed especially advantageous characteristics regarding resistance, durability, faster setting time and manufacture, material control and lower cost. There were several reasons for its popularity: social and historic aspects, but mainly economic and technical factors. The blind faith in a new modern technique brought about transformations such as the abandonment of traditional materials with the ensuing loss of qualified labour and the neglect of the original materials (stone, brick, timber and lime mortar) in the construction and restoration of masonry buildings. For that

reason, traditional building methods little by little fell into oblivion.

During the first half of the 20th century, reinforced concrete began to be used first in archaeological restoration as a supreme recourse that soon spread all over the Mediterranean region, especially Italy and Greece, after World War II. This practice was soon extensively used in the restoration of historic buildings in the rest of Europe.

In archaeological areas, the major intervention technique was anastylosis, which consists in rebuilding ruins using the original elements. This procedure, considered the purest restoration system, nonetheless depends on being able to find the original parts and knowing where they should go in the monument. The massive use of reinforced concrete was considered an essential element to recuperate and reinforce these structures (figs. 2 & 3). One of the first and most important examples of anastylosis was the intervention on the temples of the Athenian Acropolis initiated by Nicolaos Balanos in the thirties. In 1931, Balanos, in charge of the works on the Parthenon, stated that anastylosis restoration had the great advantage of using reinforced concrete which was “discreet, harmonious and respectful as a firm, solid, long-lasting element”. This new criterion was based on the text of article V of the Athens Charter (October 1931). This document contains very general restoration guidelines, but for the first time pronounced clearly technological issues in favour of using reinforced concrete. It expresses the opinion that these reinforcement methods must be disguised in order not to alter the aspect and character of the building being restored. It relies on the use of these methods, especially in cases where they permit elements to be conserved in situ, avoiding the risks of destruction and reconstruction. Article V states: “Experts approve a prudent use of all the resources of modern technology for the conservation of old buildings and especially reinforced concrete. They recommend it in cases where it permits avoiding risks of disintegration and sinking of the elements to be conserved.”

So reinforced concrete was officially accepted as a restoration material at the International Congress in Athens. Among those participating, it is worth mentioning

especially: Gustavo Giovannoni, Luigi Pernier and Amédée Miauri from Italy; Modesto López Otero and Leopoldo Torres Balbás from Spain; Pierre Paquet and Paul Léon from France; Nicolaos Balanos from Greece and Luis Ortiz Macedo from Mexico.

In general, two meaningful aspects emerged: on the one hand, the technical exaltation of reinforced concrete and, on the other, to a lesser degree, doubts about formal aspects and the visibility of the works. Most of the theoreticians that took part in the congress were enthusiastic about this new material as the only recourse for the conservation of built heritage. The influence of the new technology and knowledge of science were very important in promoting concrete. In an article written some time later, Gustavo Giovannoni pointed out that “the field of restoration is open to the contribution of physics and modern building methods, especially the use of reinforced concrete in its diverse applications”. Another speaker who had absolute faith in concrete and the new technique for restoring masonry buildings was Modesto López Otero. He said, “...the triumph is interventions with reinforced concrete; no material or building system surpasses it in plasticity, adaptability, great constructive unity, incombustibility and even economy. Besides, reinforced concrete has the curious quality that it behaves like a living being, contracting itself in places to avoid excessive stress and transport it to fatigue areas in such a way that it ends up adopting a more perfect state of equilibrium”. On the contrary, Luis Ortiz Macedo’s document contains an “alarmed perplexity about the system of reinforced concrete perforations in the Alhambra complex. Another speaker, Pierre Paquet, expressed his doubts about the use of reinforced concrete in restoration and its structural compatibility with historic buildings: “It is easy to understand the concern that can be aroused by the application of a construction system on a medieval building; it involves introducing in its extremely elastic structure elements that are essential rigid and likely to alter its equilibrium.” But at the same time Paquet mentions the advantage of this new material as a resource in restoration: “The application of reinforced concrete never

modifies the construction system in the consolidation of walls, roofs, vaults and fittings.”

In 1938, on the occasion of the reform of Italian laws about the protection of assets of artistic-historic interest and the founding of the Istituto Central per il Restauro (ICR) in Rome, a ministerial commission chaired by Gustavo Giovannoni, Roberto Longhi and Guglielmo De Angelis D'Ossat was set up. The Italian Carta de Restauro and the Istruzioni per il restauro dei monumenti emerged as a result, with guidelines similar to the Athens Charter with respect to the new materials. In Article IX it says “With a view to reinforcing the watertightness of a monument and restoring its volume, all very modern building methods can be of great aid and should be used when the use of old traditional methods do not serve the purpose.”

The different reasons for using reinforced concrete in the restoration of historic buildings were strongly influenced by two aspects:

A theoretical aspect justified and promoted by the Athens Charter: the use of reinforced concrete became “common practice, although unnecessary and thoughtlessly adopted, as it was wrongly considered easy and immediate, so much so that it very soon became seen as a banal and detrimental routine operation”.

A practical aspect: the great popularity of this material among specialists as a device to enhance the structural quality of historic buildings; “they believed this new material permitted them to resolve by scientific methods problems that traditional materials had failed to”.

This is how the use of reinforced concrete became generalised, with enthusiasm and conviction, as the major tool for the conservation of monuments in the 20th century. The conceptual position and the evolution of ideas admitted this new reintegration technique and traditional materials were abandoned for scientific criteria. Unfortunately, from this time onwards a substantial change came about in the mind of architect-restorers regarding the structural knowledge of masonry buildings.

#### USES

Some of the main uses of this new material in the conservation of archaeological beds are the reconstruction

of walls and columns by anastylosis, the support and reinforcement of bays and architraves, the injection of mortars in mural paintings and the reconstruction of roofs.

The main objective in the introduction of this new material was to provide greater resistance in archaeological remains. The operation was sometimes performed using part of the existing wall to place the rods, in such a way that the new structure became completely inserted in the building, that is, invisible, thus complying with another restoration criterion of the thirties.

To perform the anastylosis of missing elements, two types of material were used: mass or reinforced concrete (above all between 1930 and 1970) and, to a lesser degree, bricks. The concrete was more successful because the intervention was considered more “mimetic”. Anastylosis was greatly influenced by the need to differentiate between the new or added parts and the original, and concrete permitted this distinction (figs. 4 & 5).

In the fifties, this technique became common practice. For example, Carlo Perogalli sustained “the use of cement in anastylosis is useful for its straightforwardness, its plasticity and the ease with which it is made”. On other occasions, this new material was considered “opportune and efficient”. This is the way it was described by Luigi Pernier in his intervention on Phaistos (on the island of Crete), where he used this material to consolidate the structure of the pebble and earth walls.

One of the problems of anastylosis resides in its application in buildings without ashlar or cut stones, that is, structures with other building systems such as, for example, ordinary plastered masonry. For that reason, in 1973 Piero Sanpaolesi came to the conclusion that anastylosis was practically impossible because it was “necessary to resort to the reconstruction method, the difference between both methods being that the latter implies the use of new materials and even new techniques like reinforced concrete”. Paul Philippot confirmed this point of view when he said, “Anastylosis can only be contemplated when the building is made of fabric bonded without mortar, where the joints permit the exact restitution of the original form and the pieces have not

been deformed by erosion”. In Mesoamerican archaeological restoration, the pure recourse of anastylosis represents a limited conception and is too strict for construction systems with irregular masonry. Augusto Molina Montes affirms, “...this seriously hinders the restoration of Mesoamerican monuments because, with the exception of those in the northern region of the Mayan area and in Mitla, very few of them are built of or covered with uniformly-placed cut stone; most of them have roughly-hewn stones that are not laid in rows and are covered with a very thick coat of stucco”.

Another recourse used in the restoration of archaeological sites from the forties to the sixties was the technique known as *bauletti*, which was used to protect the top of walls with a mixture of Portland cement with different items like pebbles, bricks, etc. We can see examples of this in the archaeological area of Ostia, near Rome (figs. 6 & 7).

Among the first archaeological zones of the Mediterranean where we can find diverse uses of reinforced concrete as a restoration technique between the nineteen twenties and fifties, the following deserve special mention:

In Greece:

The Parthenon, Athens  
Knossos, Crete  
Lindos, Rhodes

In Italy:

Selinunte, Sicily  
Pompeii, Naples  
Herculaneum, Naples  
Villa Adriana, Rome  
Ostia, Rome

#### THE PARTHENON, GREECE

The Parthenon was built in the 5th century BC. The temple, constructed in white marble from Mount Pentelikon, is surrounded by a peristyle made up of eight columns on the east and west façades and seventeen in the north and south, a total of 50 columns in Doric style, over ten metres high and one metre wide. These columns sustained an entablature consisting of an architrave on which the frieze of triglyphs and metopes rested.

After its 2500 years' existence, the Acropolis complex has suffered serious deterioration. The first transformation took place in the 5th century AD, when the statue of Phidias was taken away and it

was turned into a Christian church. Around the 7th century, other structural changes occurred in the interior. In 1485, the Ottomans took the temple and made it into a mosque, erecting a minaret on the western side. But the most serious damage took place in 1687, during the war between the Republic of Venice and the Ottoman Empire, when a projectile set fire to the Parthenon, used at the time as a gunpowder store, causing a huge explosion. Furthermore, at the beginning of the 19th century, a large amount of the sculptured frieze was removed and in 1894 it was badly damaged by an earthquake. In the Athenian Acropolis two clearly-defined construction means, materials and methods of archaeological restoration can be seen. Eight restoration works are estimated to have taken place over the last two centuries. In 1833 the first excavation was performed. Ludwig Ross, Stamatis Kleantes and Eduard Schaubert executed the partial reconstruction of the Parthenon in 1834, the Temple of Athena Nike in 1835 and the Erechtheum in 1836. In this first phase, the missing or broken pieces were replaced with Pentelic marble. Later, between 1842 and 1845, the Greek archaeologist K. Pittakis and Alexandros Rizos-Rangabé used old blocks taken from the excavation in their intervention. Between 1846 and 1847, the French architect A. Paccard substituted brick for the marble columns in the Caryatid portico, and repaired the podium and the architrave with new blocks, which have damaged the structure over the years. Between 1870 and 1872, the Greek archaeologist P. Eustratiadis reinforced the architrave with iron bars.

*Repairs with reinforced concrete in 1930*  
Whereas in the 9th century traditional materials like marble and brick were used, from the 20th century on new techniques were introduced and that is how “reinforced concrete transformed the working criterion”. The intervention with reinforced concrete on the Athenian temples was initiated by Mr Caviadas and continued in the thirties by the engineer Nikolaos Balanos, who used this new material to replace the missing parts of columns and architraves, as the Athens Charter suggested in 1931: “in pursuit of a diversity of materials and modern techniques”.

During the nineteen twenties, Balanos used anastylosis in an attempt to retrieve the different pieces and try to put them back in the place they had occupied originally. To restore both columns and the entablature, he used iron, concrete and cement mortar. The scattered fragments of the shafts were stuck on with “an external mass of cleverly reinforced concrete, adopting the profile of the column and the large lintel with reinforced concrete girders; in this way the ruins were steady and solid”. Concrete was added to the interior of most of these shafts and some drums of the columns were sewn with iron clamps. Besides, some blocks were refashioned in cement mortar mixed with Pentelic marble powder and part of the entablature of the northern peristyle was raised. Iron girders were also introduced into the damaged blocks in the Temple of Athena Nike (1935-1940), and “reinforced concrete was used in the parts that were not visible” (figs. 8 & 9).

*Damage caused by restorations with reinforced concrete*

One of the first representative examples of this need to restore what has already been restored as a result of the serious problems caused by the concrete is the Acropolis in Athens. In 1971, at the first international congress about the deterioration of stone, Theodore Skoulikidis explained that the “successive restorations of the Acropolis, where the marble was fortified with elements of reinforced concrete and iron, present serious degradation; I recommend it be replaced by titanium”. Specifically, the Parthenon was the first archaeological building that required urgent measures because of damage to the original materials. This temple began to show extremely serious disintegration and breakages due to rust in the iron, which could be seen in several places. It had only been forty years since the interventions with reinforced concrete and it already needed other works to correct the problems caused by this material. The original marble of most of the columns of the Parthenon, especially the shafts that had added parts, showed signs of serious oxidation and deterioration. For this reason, an investigation campaign was put into practice to find out what problems were arising so as to replace in the most suitable manner the concrete prostheses introduced by Nikolaos Balanos. An

exhaustive study was initiated, during which it was decided to remove the concrete where possible and replace it with other more compatible and long-lasting materials.

In the nineties, modifying the intervention criterion to show respect for traditional materials, the architect Manolis Korres and the archaeologist Tupula started to use the white marble from Mount Pentelikon, taken from the same quarry used by its creators 2500 years earlier (fig. 10). Speaking about this marble, Professor Paolo Marconi said, “it could have problems caused by atmospheric contamination, but the structure will never be weakened in the way it is with reinforced concrete”.

In mid 1999, the Central Archaeological Council of Athens decided to approve a broad restoration project that included the reconstruction of several marble columns in the Parthenon; eight of the columns – from the fourth to the eleventh – had to be dismantled because their iron interior was becoming rusted and their surface had fissures due to erosion and the incompatibility of the materials added; 14 column drums were also replaced. Both the engineer-restorer Kostas Zapa and the president of the Acropolis Restoration Committee, Haralambos Buras, informed the Central Archaeological Council about the need for this restoration. “With today’s technology, the recuperation would be much better than Balanos’, for all the pieces and fragments of concrete and iron would be removed, and many pieces were found that had been lost.” To free the Parthenon of the parts added in the thirties, “we calculate that between the cement reinforcement of the columns, the iron clamps between the ‘rings’ of each column and other additions, over 145 tons of material will have to be removed from the famous monument”.

For the late 20th century restoration works several tons of Pentelic marble from the original quarry and numerous titanium pins were used. Five Doric column rings were sculpted out of marble and, among other operations, 200 fragments of the original monument that were scattered about the Acropolis were put back in place. Other monuments are being restored too, such as the Propylaea that gave access to the archaeological site and the Ionic temple dedicated to Athena Nike.



In the latter, the iron pieces used to strengthen the marble and the blocks underneath are being replaced with titanium elements. These actions will help restore the original appearance of the temples, correcting past errors and the varied reconstruction processes.

Regarding the situation of the Parthenon, when the reinforced concrete prostheses were removed in 2005, the archaeologist Fani Malouhou mentioned, “to our surprise, during the works we realised that the damage caused by earlier restorations is worse than we had previously thought, and that made them take special care with the works performed on the Parthenon. Because there are static problems that hinder the work.” Fani Malouhou emphasises that the main difficulty in the intervention “is to replace the old iron bars in the columns with titanium ones. The iron is rusted and threatens to burst the columns. A fact that is added to the concern of the archaeologists and architects working on the old polis of Pallas Athena: they do not know exactly the state of the marble in the interior of the columns.” Apart from the serious errors committed in the restoration with reinforced concrete, in recent times the archaeological site is in grave danger from massive tourism and pollution.

#### KNOSSOS, CRETE, GREECE

Knossos, the most important city of the Minoan civilisation, lies on the island of Crete in the Aegean Sea. The most emblematic building in this archaeological zone was the Palace of Knossos, with 17,000 m<sup>2</sup> and more than 1500 rooms. The first palace was constructed around 2000 BC and destroyed by an earthquake in 1700 BC. The second palace was reconstructed in 1600 BC, but another earthquake razed it in 1400 BC and it was abandoned. In this historic reconstruction the earlier architectonic scheme was respected but the techniques used were better. The walls were erected with ashlar that served as a support for the fresco decorations and a sewerage system with terracotta pipes. The remains at the archaeological site bear witness to the existence of a society with a higher development level than in continental Greece. The complex was arranged around a large central patio, 58 x 28 metres, and divided into two parts, east and west,

separated by two entrances in the north and the south. The west wing housed a series of official and religious rooms, like the Throne Room or offering deposit, storerooms and workshops. The east wing contained private rooms, with a maze-like layout, where from a central staircase paths forked off to decorated halls like the Queen’s Megaron. Access to the palace from the western patio was through a covered corridor with a relief fresco depicting bull-leaping. After going through the door, one came to the procession corridor, a large passage with two ways out, one towards the Southern Propylaeum with a large staircase and the other towards the Large Central Square. Because of the Minoan way of building, consisting in adding on rooms as they went along, these corridors are not linear but laid out at random in meandering fashion.

The walls of the first Knossos Palace were built on a masonry socle with timber hoists, the same material Minoans used to make the shafts of the columns, probably because they were aware that timber was more elastic and would resist the frequent earthquakes on the island better.

The archaeological excavations were started in 1878 by the Cretan Minos Kalokairinos, but the systematic excavation was carried out between 1900 and 1932 by the British archaeologist Arthur Evans. The work was only interrupted in those years by World War I. From 1920 to 1935, the archaeologist published his work in six volumes entitled *The Palace of Minos at Knossos*.

#### *Restoration with reinforced concrete from 1900 to 1932*

There were two important stages in this archaeological area, the first from 1900 to 1910, when the work focused on the archaeological findings and the protection of the remains. In a little over two years the whole palace was excavated, and the Throne Room, the Central Square, the Large Staircase, the storerooms and the royal chambers were successively discovered. On the contrary, in the second, after the twenties, they carried out “one of the most intensive reconstructions in reinforced concrete that was ever attempted on an archaeological site”. According as the English researcher advanced with the excavations, he

observed that the timber girders and columns that held the upper storeys of the palace deteriorated very rapidly after coming into contact with the air, so that the excavated areas required protection. For this purpose, Evans did not hesitate to use cement-covered iron girders, which were especially aggressive in the context in which they were inserted. The archaeologist stated in 1925 that “the growing use of reinforced concrete with iron rods to build all sorts of elements opened up a new era of reconstruction and conservation in Knossos Palace”. As a consequence of this faith in concrete, the structural system of the walls was replaced by a new one made with girders and frames made of this material, as these modern elements had the virtue of adopting the same shape as the old ones. Iron girders, reinforced concrete and wood from the Tyrol in Austria contributed to create the vision Sir Arthur Evans had of the legendary palace of King Minos (fig. 10).

In the Throne Room we can see the different restoration periods and criteria. In 1901 the remains were covered with a flat roof held up by brick pillars and wooden columns. In 1904 the flat roof was replaced by a hipped one with a metal structure. Finally, in 1930 the remains were replaced with a new building with elements made of reinforced concrete (pillars, girders and frames).

#### *Damage caused by restoration with reinforced concrete*

Quite a lot of controversy has arisen about the reconstruction of Knossos. One of the first to be documented was that of Cagiano de Azevedo in 1948, which rejected the criterion applied in the reconstruction “under the dubious and hypocritical affirmation that, since the recognisability of the old part is diminished, it is legitimate to refashion everything that is missing, although its modernity does not deceive anyone”. In 1975, Augusto Molina said, “Evans started his works in a conservative manner but, infected with a disease that seems to be endemic to those who dedicate themselves to restoration, became more venturesome and ended up producing architectonic images that he himself had conceived, achieving constructions of a phantasmagorical nature that fascinated

the general public, considering not the original ruins but the reconstructions that cover a large part of them as the Minoan Knossos; enthusiastic about the vision of his own creation, he never realised how like a film set his reinforced concrete reconstructions looked.”

The restoration performed by Evans, under the supervision of the British architect Christian Doll, has been severely criticised not only because of his unsystematic excavation method and the creation of several elements and the decoration of the building with no archaeological documentation, but also because of the materials used and their poor durability with the passage of years. Research was carried out in the archaeological site of Knossos in 1990 about the effects and chemical pathologies the reinforced concrete were causing, with the participation of various scientists, including, among others, A. Bakolas, Guido Biscontin, P. Maravelaki, T. Markopoulos, E. Repouskou and Elisabetta Zendri. The scientific exploration campaigns were aimed at assessing the degree of degradation of the interventions with this material. Different chemical and physical studies were carried out, such as: porosimetry, X-ray diffraction, spectroscopy, etc., with a view to discovering the current state of the concrete components. It was found that the minerals present like: portlandite, tobermorite and hydromagnesite indicate a sudden transformation of the adhesive and the negative effects of the durability of the concrete (fig. 11).

The following are the most significant among the points of interest regarding the assessment of the reinforced concrete in the restoration of Knossos:

- The state of conservation presents a certain amount of alteration in the carbonation of the elements because of the high percentage of carbon, which reduces the thickness of the concrete and therefore the rods are badly rusted.
- The original materials that contained a large amount of gypsum were replaced by a mixture of Portland cement that reacted by forming ettringite.
- The hydromagnesite presents important indications of mineral transformation due to the influence of carbonic anhydrase.
- The reduction of Ph in the mixture and the presence of portlandite.

-An increase of porosity due to the action of environmental degradation.

#### LINDOS, RHODES, GREECE

Lindos is a city located on the east coast of the island of Rhodes. It was founded by the Dorians in the 10th century BC. Rhodes' location made it a natural meeting place for Greeks and Phoenicians, and in the 8th century BC it was an important trade centre. Besides, this city was still important also from a religious point of view, because it had two sanctuaries, one to Athena Lindia and one to Heracles. Above the city lies Lindos Acropolis, a natural citadel fortified successively by Greeks, Romans, Byzantines and Ottomans. In classical times, at one end of the acropolis and on the highest spot on the hill the enormous Temple of Athena was built, taking its final shape around the year 300 BC. It measured 21.5 by 7.75m and had a portico of four Doric columns on each of the shorter sides, like the Temple of Athena Nike in the Acropolis of Athens. In Hellenistic and Roman times, the temple area grew and this was when most buildings were added. At the beginning of the Middle Ages, these buildings fell into disuse, and in the 14th century they were partially covered by a fortress erected on the acropolis by the Knights of St John to defend the island from the Ottomans. Today important archaeological remains are conserved, the most outstanding of which are the theatre and the two temples, to Athena Polias and Zeus Polieus.

#### *Restoration with reinforced concrete*

Excavations were carried out at Lindos in the years 1900 to 1914 by the Carlsberg Institute of Denmark, directed by K.F. Kinch and Christian Blinkenberg. The acropolis site was excavated down to bedrock and the foundations of all the buildings were uncovered. During the Italian occupation of the island (1912–1945), major restoration work was carried out on the Lindos acropolis. The north-east side of the Temple of Athena was restored by anastylosis, using concrete. The monumental staircase to the propylaea was rebuilt and many of the columns of the Hellenistic stoa were re-erected. The archaeologist Giulio Jacopi also used reinforced concrete in covering large surfaces of the site; bases and inscribed blocks were taken from their

locations and placed along the restored walls.

#### *Damage caused by restorations with reinforced concrete*

This is one of the first examples where the new material, combined with the old one in very poor condition, did not give a good result and was unable to avoid its collapse in 1966, documented by G. Pavan. From 1989 onwards, research campaigns were performed because of the serious deterioration of the original structures at Lindos; serious damage was found to have been caused by excessive use of reinforced concrete during the anastylosis of the four Doric columns in the Temple of Apollo in the thirties. Professor Theoulakis, who carried out the study, had this to say about these interventions: “Unfortunately, some of the methods and techniques applied broke certain restoration rules, such as putting reinforced concrete with iron rods and Portland cement in contact with the original stones. These materials caused great deterioration of the original elements, serious cracks in the columns and architraves and degradation of the stones from the soluble salts in the cement.”

The following were some of the main examples of deterioration:

The stones in the columns were joined with cores of reinforced concrete, a solution that goes against the concept of Doric architecture since it deprives them of their original movement:

The soluble salts in the Portland cement brought about rapid deterioration in the limestone.

The iron rods show oxidation, marine corrosion and an increase in volume. The reinforced concrete additions are more rigid than the original stones, thus causing cracks and disintegration; from a mechanical point of view, great stress is produced during earthquakes.

The new architectural elements were reconstructed with reinforced concrete, covered with a mortar that imitated the aesthetic features of the original stone, which meant:

The oxidation of the rods caused cracks in the concrete and disintegration of the coat of mortar.

Rapid deterioration of the original architectonic elements when rainwater

reacted with the soluble salts in the Portland cement, producing large stains. Some elements were filled in with artificial limestone. This technique was less harmful than the reinforced concrete, but did not satisfactorily reproduce the physico-mechanical properties of the original stones, because stone is less porous and more resistant.

The behaviour of the reinforced concrete structure is very different from the original structure from a mechanical point of view and caused serious problems to appear after earthquakes, among them large cracks and gaps in the areas where reinforced concrete had been used. The main cause is that this material modifies the flexibility of the original structure and makes it more vulnerable to seismic phenomena.

In recent years, archaeologists from the Greek Ministry of Culture have worked on the restoration and protection of the old remains of the Temple of Athena. These archaeologists have corroborated that the massive use of these restoration materials failed to care for the surviving architectonic remains. The increasing affluence of tourists adds to the problem.

#### SELINUNTE, SICILY, ITALY

Selinunte was founded in the mid 7th century BC. It is situated in the province of Trapani on the west coast of Sicily. It is one of the most outstanding archaeological sites in the Mediterranean, and above all the largest Greek of the beds. In 409 BC the city was under siege for nine days by a fleet of 100,000 Carthaginians; during that battle most of the temples were plundered and many buildings were destroyed. It was also damaged by consecutive earthquakes. In the year 1551, the historian Fray Tommaso Fazello discovered the site. Two centuries later, Ferdinand II of Bourbon dictated a decree forbidding pieces to be taken from the site. But it was not until the 19th century that the archaeological works began and the archaeological ruins were identified.

The current archaeological complex is divided into four zones: the Eastern Temples, the Acropolis, the Old City and the Sanctuary of Malophoros. The Eastern Temples, situated at the eastern entrance, best represent the importance of Selinunte. On the eastern hill stand temples E, F and G. Temple E, in Doric style, with pronaos,

naos and opisthodomos, was built at the beginning of the 5th century BC. Temple F was built between 560 and 540 BC, and is in complete ruins. Temple G had a colonnade of 46 columns 16 metres high and a circumference of 10.5 metres, and is one of the most impressive temples of ancient times. Building started in 580 BC and, a hundred years later, when the city was destroyed, it still had not been finished. Today a column restored in 1832 stands alone so that visitors can imagine the magnificence of the temple. Facing the sea on an irregular esplanade stands the Acropolis, with an important defensive system of walls and towers. The Northern Gate is flanked by two rectangular towers, with a moat and semicircular turret in front. Inside are temples A, B and C. Near the sea, Temple A with a peripteral hexastyle plan, dates from 490 BC. Temple B has Ionic columns and a Doric frieze. In 1824, the German-born Jacques Ignace Hittorf discovered the polychromy of this temple. Temple C, erected on the esplanade of the Acropolis, dates from the 6th century BC and has 6 columns at the front and back and 17 on each side. The layout of the dwellings in the Acropolis followed an orthogonal pattern, the north-south axis being the most outstanding.

#### *Restorations with reinforced concrete in 1930*

Anastylosis was also used on this archaeological site. An example of this was the reinforced concrete girders concealed in Temple C. The person in charge of this restoration was Francesco Valenti, who in 1928 carried out anastylosis as complete as the ruins permitted. This intervention consisted in erecting 15 columns, many of which had complete capitals. At one side of the temple he placed a long stretch of entablature whose inner structure was made of reinforced concrete. This work received unanimous approval and is still hailed as an example of good anastylosis. Later, in the fifties, Jole Bovio Marconi restored Temple E by anastylosis of the pillars and put in place the pieces of the base that were scattered about on the ground (figs. 14).

#### *Damage caused by restorations with reinforced concrete*

J. B. Marconi's intervention on Temple E has been harshly criticised by numerous

authors because they think the restoration was excessive and unjustified by the elements that had survived, "but above all because of the amount of reinforced concrete used to reintegrate the replaced parts by anastylosis". Cesare Brandi had this to say about this intervention of the sixties: "It was even necessary to alter the structure drastically with reinforced concrete, in such a way that neither the aesthetic nor the historic requisites were complied with. It would have been better to preserve the remains of the temple in the state in which the passage of time had left them." Finally, Cesci insisted that "the use of reinforced concrete was excessive" (fig. 1).

In 1978, Franco Minissi said that "it was necessary to avoid any solution that would be unchangeable and irreplaceable; when the addition of concrete involves a particularly invasive preparation where it comes into contact with the original matter (frame to attach the new concrete part to columns or capitals), the argument of reversibility no longer makes sense, for example in Segesta, Selinunte".

#### POMPEII, NAPLES, ITALY

The ancient city of Pompeii (south of Italy) dates from the 6th century BC, when the city was inhabited by settlers of Etruscan origin. The temples of Apollo and the Doric Temple in the Triangular Forum date from this period. After 310 BC, when Pompeii became an ally of Rome, a great deal of building took place, during which the Doric Temple was restructured, the cult of Apollo was renewed and a new wall began to be erected.

Pompeii and Herculaneum, two very important archaeological sites of classical culture, were destroyed in the year 79 AD by an eruption of Vesuvius. The ashes encapsulated and preserved the buildings and layout of the city. In 1748 they were discovered, and provided valuable information about the lifestyle of the ancient Roman Empire. Giuseppe Fiorelli, superintendent of Pompeii between 1863 and 1875, insisted that the elements discovered there be left where they were, and evaluated for the first time all the types of constructions, from the humblest abodes to the villas and palaces whose walls were covered with murals. Amedeo Maiuri, who occupied the same post from

1924 to 1961, continued to apply the same conservation criterion and did not allow objects to be taken from the ruins where they were disinterred.

The archaeological site of Pompeii is famous for its domestic architecture, with adobe fabrics, interior mud-plastered wattle walls and timber and stone balconies. Since it was discovered, some damage has been caused to its constructions, among others, by: seismic movements, bombing in the Second World War, climatological factors (changes of temperature between summer and winter), problems connected with the conservation of the materials and inadequate interventions carried out from the thirties to the eighties, with the application of materials like reinforced concrete. This new material was lavishly used in the reconstruction of walls and roofs, in supporting and strengthening bays and injecting mural paintings.

#### *Damage caused by restorations with reinforced concrete*

From the nineteen eighties onwards, serious problems began to arise as a result of the excessive use and bad behaviour of this new material. The 1980 earthquake caused serious damage in the structures and roofs of the following houses: Giulia Felice, Vetti and Nozze d'Argento. Problems arising from the poor work with reinforced concrete and the rigid behaviour of this material compared to the original structures could be seen at first sight. From then on, it was deemed important to perform studies about the damage caused and strive to resort to traditional techniques using materials more similar to the original ones. In 1995, the Soprintendenza Archeologica and the Istituto Centrale per il Restauro made several analyses. One of them was on the roofs that had been replaced with reinforced concrete. The aim was to diagnose the causes of their state of degradation by performing tests on the materials added and a detailed structural analysis according to current regulations. In most of the roofs rebuilt with reinforced concrete a high degree of degradation was found, due to three interrelated factors: The atmospheric agents caused oxidation of the frames, which was worsened by insufficient protection and maintenance. Project errors and incongruence in the

technical construction, by using short-lived typologies like SAP frames (typical in the postwar period).

The poor quality of the materials used.

#### *Casa di Giulia Felice*

The roof of the house was repaired with reinforced concrete during the forties and fifties and at the end of the 20th century had already fallen into a state of advanced deterioration, with evident disintegration and corrosion of the bars. The roof had sagged and was propped up in several places. Studies were performed and confirmed the precariousness of the structure, the poor technical level of the works performed and the bad quality and result of the materials used – especially due to the use of reinforced concrete – and incongruence in the technical construction. Finally, after analysing the current state, it was decided to demolish as much as possible of the concrete structure and to build a new roof like the original one. The roof of the portico had also been replaced with reinforced concrete at the same time. Currently, the state of conservation of the original elements of the portico – the marble columns – is good because the original material was not replaced. However, the concrete roof of the portico did show signs of superficial deterioration. The barrel vault of the baths, which had been repaired with reinforced concrete, also presented damage like fissures and cracks.

#### *Casa dei Vetti*

Starting in 1927, the works to replace the timber elements lining the iron frames in the atrium and the peristyle with other types of wood like fir and pine were initiated. This went on until 1954, when they began to use reinforced concrete on the roof, both for the purlins and the tiles, prefabricated out of the same material. Now this concrete roof was badly degraded and pieces of the material had come loose because of the oxidation of the metal rods. Several laboratory tests were carried out to determine the mechanical characteristics of this structure. It was found that:

- The principal girders had a section of 35 x 53 cm. Their length complied with the current regulations, but that of the haunches did not, although it did comply with the rules of that time.

- The header beams of the compluvium had a section of 30 x 38 cm and were armed with 20 no. 4 rods and 16 rods in the lower bed. The upper bed could not be measured because the other structure was in the way. The longitudinal frame was within the requisites of the regulations, unlike the no. 8 haunches every 30 cm.

- The purlin section measured 12 x 15 cm and they were armed with 4 no. 8 rods in the lower bed, 3 no. 8 rods in the upper bed and no. 6 haunches every 45 cm. The number and layout of the longitudinal rods would even comply with today's standards, whereas the haunches were poor even by the standards of the time. The lower rods were badly corroded and the adherence between the iron and the concrete is poor.

From the calculations, tests and observations carried out, the conclusion is that the concrete is suffering serious stress, to the limit of its mechanical characteristics. Specifically, Salvatore D'Agostino says "the structure presents incongruence in the project and execution, some girders are too big while others are just within the admissible limits; there are numerous problems about conservation and SAP-type concrete girders, which have given a very bad result to judge from the presence of serious disintegration, corrosion and oxidation" (figs. 15 & 16).

#### *Casa delle Nozze d'Argento*

The atrium of this house also showed signs of damage caused by replacing the wooden roof with a reinforced concrete one in 1978. The structure comprises four principal girders, the girders of the compluvium and the smaller joists. It is important to underline the fact that, unlike the interventions performed on the other houses in Pompeii, here the reinforced concrete structure is still in a good state of repair, possibly because it was made fairly recently, only thirty years ago. The studies showed that there were no deformations and the material was intact. Therefore, D'Agostino said, "twenty years after this work was done, there is adequate structural efficiency, which must be ensured by means of continual maintenance".

As a conclusion to his studies in Pompeii about the durability and efficacy of concrete as a material for restoration in the 20th century, D'Agostino says "after all,



unlike traditional elements, modern reinforced concrete elements need urgent repairs. After fifty years these repairs and even the complete removal of the reinforced concrete structure are inevitable, both because of the difficulty involved in its recuperation and in order to safeguard other parts of the houses, whose conservation is compromised by the degradation of this structure.”

Among the different tasks performed on the archaeological site of Pompeii and Herculaneum, harmful materials have been eliminated in: the reconstruction of walls and partitions, cement has been replaced by hydraulic mortars made of lime, pozzolana and sand, mixed with fragments of stone or brick. These interventions can easily be identified because they are at a lower level. In the consolidation of the rendering, injections of several types of lime mortar have been used, mixed with brick powder, aggregates and, in some cases, synthetic additives. In mural paintings, attacked to a large extent by microorganisms and surface salts caused by Portland cement, organic products have been used to substitute synthetic resins. These layers were removed by mechanical and chemical means. On the roofs, the prefabricated concrete tiles were replaced by the clay tiles known as Pompeian, similar to the original ones. Another material that was abundantly used is laminated fir wood, both for roofs and woodwork fittings. “Nowadays it is used in roofs, tassels and bays instead of cement girders, for it provides greater stability from a technical point of view and as regards mechanical resistance, and looks very similar to other aesthetic construction items; to reinforce bays, the ends are lined with sheets of lead to protect them and, where necessary, to make it easier to replace them” (figs. 17 & 18).

#### EVALUATION OF THE CURRENT STATE OF REPAIRS WITH REINFORCED CONCRETE

Unfortunately, the durability of these interventions in the archaeological sites analysed in Italy and Greece did not live up to expectations, because in the eighties they started to deteriorate rapidly. The most important pathologies to a greater or lesser degree were: weakness, fissures, fractures and breakage of the elements in contact with the concrete, especially when it was

reinforced. In most cases, there was serious degradation in the architraves of the porticoes, disaggregation of materials, corrosion of clamps and the constant presence of salts in the marble blocks, all as a result of the oxidation of the iron and the carbonation of the reinforced concrete.

Another factor found to have affected these sites was the passage of time. Fifty years after these works, the real behaviour of restorations with reinforced concrete in most cases had not been very good but, on the contrary, the modern prostheses were found to have aged a great deal and the materials to have interacted very badly with each other. Incompatibility was detected with elements both because of the intrinsic characteristics of the materials and building errors (in execution techniques and the quality or quantity of material). Besides, three pathologies were found in connection with the durability of the concrete: physical, chemical and mechanical incompatibility. No doubt this trial period was the best tool to measure and evaluate the effectiveness of these interventions with reinforced concrete (fig 19).

In the mid nineties there was an increase in the number of specialists who advised against the use of reinforced concrete because of the continual problems it was causing and because they thought this technique was not so long-lasting, compatible, reversible or authentic with built heritage as expected.

After observing the damage caused in archaeological sites, a change of mentality has started to come about regarding the criteria of intervening with reinforced concrete. The main objective is to stop abusing a technical recourse as though it were the only formula to solve the problems of historic buildings without knowing exactly how the two materials would interact with each other. The application of reinforced concrete has definitely not been the “magic solution” it was believed to be in the second half of the 20th century, but its influence has been so great that, apart from modifying the conception of building for many years, it is still used in some works. This way of restoring with new materials without knowing what the consequences will be must be modified, especially as it has already caused great deterioration and incompatibilities both in archaeological sites and historic buildings and has

brought about irreversible degradation (figs. 20 & 21).

In general, after observing the deterioration produced by reinforced concrete, the new intervention criterion both in archaeological sites and historic buildings is focusing on the recuperation of traditional techniques, with the use of natural materials with composition and behaviour similar to the old ones, easy to apply and, above all, enduring. It is important to keep seeking alternatives, without applying them as standard practice but as partial solutions in each case, demythologising modern materials, transforming the short-term vision of the work and habits of all those in charge of safeguarding our heritage, introducing a methodology about the analysis of damage, recuperating and assimilating knowledge of traditional techniques and thus understanding better the structural behaviour of historic construction. Today, after evaluating the current situation of concrete in 20th century restorations, its use should be limited, because only a correct choice of materials and their ideal application will manage to avoid greater alterations in our heritage.



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#### CONSERVATION OF THE SOUTHERN FAÇADE OF HORNÍ HRAD OF THE ČESKÝ KRUMLOV STATE CASTLE

##### SITUATION, HISTORICAL DEVELOPMENT AND IMPORTANCE OF THE MONUMENT

The ancient town situated in South Bohemia in the land close to the Austrian border (180 km from Prague) and founded on a dramatic land configuration close to the Vltava River is one of the most outstanding monumental sites in the Czech Republic. The historic mediaeval urban area contains an extensive group of precious historic buildings (burghers' houses, council buildings, monasteries and churches) and is harmonically located in the picturesque framework of the landscape.

Dominating the historic town is the large complex of the state castle, which is one of the most attractive and most frequently

visited monuments in the Czech Republic. For its importance and size, it ranks among the most important residences of the Czech Republic, second only to Prague Castle, and among the foremost monuments in Europe.

Due to its exceptional artistic and historical values, the old centre of Český Krumlov was declared a Municipal Conservation Area in 1963 and the castle area was declared a National Cultural Monument (the highest level of protection of monuments in the Czech Republic). In 1992 Český Krumlov, including the castle area, was included in the UNESCO World Cultural and Natural Heritage List.

The Gothic castle in what is known as the bergfried type (a defensive watchtower) that was built on the rock above the River Vltava was founded by the powerful Vítkovci family in the mid 13th century. Its high cylindrical tower, adapted during the Renaissance, has formed the dominant feature of the castle and the surrounding territory until today. From 1319 to 1331, after Český Krumlov became the main seat of the Rožmberk branch of the Vítkovci family, which it continued to be for 300 years, Petr of Rožmberk extended his residence and erected a monumental aristocratic building called Horní hrad (the Upper Castle) on the rocky ridge above the Vltava River. Horní hrad underwent a major transformation in the fourteen forties, when Oldřich of Rožmberk extended it towards the west by adding further palaces and protective elements. The new built-up area of Horní hrad was again adapted at high cost after 1500. The gradual upsurge of the Rožmberk dominions not only involved a further extension of the vast castle during the late Gothic period but also its subsequent transformation into a grand Renaissance seat. The imposing reconstruction and remodelling was carried out around the middle of the 16th century and from 1575 onwards was directed by Baltazar Maggi de Aragno with the participation of the painter Gabriel de Blonde, the author of the decoration in the courtyard of Horní hrad. The last member of the Rožmberk family, Petr Vok, sold the castle in 1602 to Emperor Rudolf II, who handed the estate over to the Eggenberg family. At the end of the 17th century, under their rule, extensive Baroque adaptations of the castle were performed, and Horní hrad

was increased by the addition of a whole new floor. In 1719 the chateau area and the whole estate was in the hands of the important Schwarzenberg family. Prince Josef Adam of Schwarzenberg was responsible for the significant remodelling works that further enriched the chateau area especially. Between 1744 and 1767 the interior of the chateau chapel was refurbished and the masquerade hall was decorated with illusive paintings by Josef Lederer. The building activity of the Schwarzenbergs also included the development of the territory outside the residence itself, especially in the western foreground of the castle where the garden was first of all enriched by the addition of a number of excellent constructions and works of art. Under the rule of Josef Adam Schwarzenberg, the riding-school was built, the chateau theatre was rebuilt and the multi-level road of the bridge Na plášti that connected the residence with the western foreground of the chateau area was adapted. In the mid 19th century, the building development of the chateau area was practically completed. In 1947 the Schwarzenberg property was taken over by the state.

#### THE CARE OF THE SITE AND ITS UTILISATION

Painstaking attention is paid to the care and maintenance of the site, which is directly handled by the National Institute for the Protection and Conservation of Monuments and Sites. It is mainly used as an important museum. This important monument is also used for a number of professional, social and cultural activities, including four festival projects (concerts, social meetings, garden fetes, experimental presentations of dramatic productions in the chateau theatre, professional workshops, etc.). Since 1990 the restoration works have intensified. They are financed by the state, grants and sponsors' contributions. An extraordinarily demanding task was the stabilisation project of all the extremely valuable authentic façades of Horní hrad started in 2002.

In 2004-2005 the challenging conservation works were performed on the southern façade of Horní hrad. The value of the fabric, the complicated technical conditions, the need for maximum circumspection together with the

enormous dimensions of the façade (ca 100 x 40 m), made it even more important to select the conception of all the interventions with great care.

#### CONSERVATION OF THE SOUTHERN FAÇADE OF HORNÍ HRAD, ITS PROGRESS AND RESULTS

##### *Conception of the interventions*

Horní hrad in Český Krumlov stands on rocky ground above the Vltava River and the vast area of the southern façade, gradually increased and transformed from the 14th century till the Baroque period, distinctly shows typical signs of stratified architecture. The traces of the adaptations, reconstructions and additions, characteristic of which are the gradual arrangement of volumes of masses and diversity of style in the details, have been preserved on the façade clearly visible until the present time. The southern façade of Horní hrad can best be viewed from the historic town and from a distance.

The great artistic and historical value of the area and of all its façades demanded great respect, in the overall conception, for the authenticity of the façades and their specific historic and aesthetical characteristics. For the repair works to be performed in several stages, the following principles were formulated:

- maximum effort would be made to rescue of the original elements and materials that were still preserved;
- the repair and conservation interventions performed with the chief aim of extending the life of authentic materials would not deviate from the practice of traditional technologies;
- change in the essential appearance of the monument would be inadmissible; therefore the inevitable repair interventions would be visually suppressed, i.e. incorporated aesthetically into the whole in such a way that the impressive original façades would not be altered;
- no corrective interventions that would eliminate traces of development and interfere with the unity of style would be carried out;
- the works would be performed by an experienced firm with the direct participation of freelance restorers in the different fields while respecting the strictly defined work methods and processes;

- the works should be completed by the end of September or interrupted and renewed under more favourable climatic conditions in the following season. After thorough preparation, in 2003 a pilot project was drawn up for the conservation of a small section of the western façade of Horní hrad. In compliance with the predetermined conservation criteria and taking advantage of the experience of the successful works carried out on the western façade, a detailed preservation project was prepared for the subsequent conservation of the dominant prospect – the southern façade of Horní hrad of Český Krumlov Castle. Given the value, character and condition of the materials, extraordinary attention was paid to the works and the overall consolidation intervention was carried out in two stages, in 2004 and 2005, treating each individual part of the original fabric.

*Condition of conserved materials of the southern Façade and their treatment*

The initial condition of the façade before repair showed a great degree of authenticity, which was rather surprising because the whole façade had not received maintenance or major repair works for an extraordinarily long period (at least since the middle of the 18th century). Exceptions to this were the partial interventions performed on the lower parts above the rocky outcrop in the nineteen seventies and minor modern adjustments. However, it was especially surprising that this monument had not been affected by the destructive interventions of the last fifty years that have often accompanied and unfortunately still accompany so-called overall renovations.

On the articulated and exposed southern façade very diverse technical conditions were found in materials and structures, with the existence of stable materials and also seriously damaged areas. More serious defects were also detected, especially in the sculptural parts of the façade: oriel windows, buttresses, counterforts, etc. All the technical interventions were performed preferentially by putting into practice the appropriate classical craft procedures with traditional materials, based on the conservation plans drawn up after the surface of the façade had been made accessible and examined from the scaffoldings.

On the surface of the southern façade there were mainly extensive areas from the Gothic and Renaissance periods, and Baroque lime mortar was found in the rendering of the upper floors. The original mortars were characterised by different thicknesses, a different application method and different surface treatment as well as a slightly different composition, depending on the period of their origin. These aspects, together with the differences in the type of masonry (stonework or brickwork) and the different exposure to the elements of partial surfaces also influenced the extent of deterioration. Apart from continuous, integral, solid and indeed unaffected rendered surfaces among which the mediaeval material was found to be considerably resistant, there were a number of details caused by the building development of the façade and the methods used (construction techniques and additional works without scaffoldings). Different exposure to the elements in certain parts along with the different age and quality of the mortars has led to the preservation of more or less extensive or fragmentary remnants of lime paints in different shades, along with the remains of more elaborate artistic decoration. At the foot of the façade, the mortar or bare masonry was covered by cement plaster during a partial consolidation intervention on the bedrock in the nineteen seventies. An increase in the humidity of the structures and a high content of soluble salts under the cement plaster and on its outer layer led to the destruction of the originally very strong and high-quality mediaeval mortars and also to partial damage to the masonry fabric. At the same time as technical stabilisation was carried out, it was also desirable to eliminate the traces of some non-essential provisional interventions recently performed (e.g. the removal of modern metal sheets from the roof to recuperate the tile roofing, the removal of the concrete cover of the walled shaft at the eastern side of the façade, etc.).

*Rendering conservation and filling-in*

Most of the conservation activity involved the treatment of historic rendering consists in its consolidation, stabilisation and partial completion being kept to an absolutely minimum. With regard to the

different stages of conservation, after the building of scaffoldings and the start of detailed examinations, attention was primarily focused on the recuperation of those subtle details that were in the greatest danger of being destroyed. The conservation was preceded, first of all, by the securing of vulnerable rendering performed by the freelance restorer (filling and reinforcement of precarious edges of mortars, providing mechanical stiff gauze supports where needed, grouting of detached interfaces in the rendering and between the rendering and the wall). At the same time, the painstaking removal of ugly concrete rendering and patches at the foot of the façade was performed. After securing the endangered surfaces, traditional technology such as lime wash, which had been tested for over ten years on similar monuments, was selected to treat and consolidate the rendering. It took some time to apply gradual repeated cycles of lime wash treatment on the historic rendering and fill in the gaps of the whole façade because of the unpredictable weather conditions. The lime wash treatment was performed to achieve the re-alkalisation and strengthening of the cohesion of the historic rendering and, at the same time, to prepare the masonry before the application of new mortar supplements and their subsequent lime wash treatment on the exposed southern façade. The systematic, daily and continuously-checked lime wash treatment and consolidation was performed throughout the whole repair period, or during the period demarcated for the performance of wet processes, i.e. from the end of May up to the middle of September. According as it took effect, at the final stage the lime wash was concentrated only on those surfaces where the condition of the material required a larger number of treatment cycles. In some places as many as 150 cycles were applied to the surface of the façade. The maximum simplification of lime wash transported to the different levels of the scaffolding, the timely beginning and good organisation of the work, including continuous verification of the efficiency of the consolidation process, guaranteed the observance of traditional technological methods and the compatibility and repeatability of the treatment of the authentic rendering. The consolidation of

the individual sections was completed with efficiency tests and detailed verification of the condition of the rendering after the intervention by inspecting the whole surface of the façade. The rendering supplements whose extent was limited to the stabilisation criteria were made of mortar whose composition was determined by a laboratory analysis of the original materials, including the historic admixtures employed for improving its properties (charcoal, crushed brick, etc.) and natural pigments.

#### *Conservation of stone elements*

As part of the stabilisation of stone details (including partial adjustments of loosened joints), it was necessary to assess responsibly, in each individual case, to what extent repair works were necessary in order to prevent the authenticity and communicative ability of the relevant part from being thoughtlessly eliminated by a stereotypical approach. All the stone elements were treated – window surroundings, consoles, discharge chutes, pavement and balustrade of the staircase buttress, stone covers of counterforts. They were mostly treated by means of minimum interventions that respected the existing condition, including additional historical adjustments, old coatings or their remains. During conservation, traces of minor damages and the degree of abrasion of each individual element were also respected.

#### *Conservation of ferrous metal elements and stained glass windows*

Regarding the preservation of the façade, it was necessary to assess the condition of the iron elements and select the most considerate approach for the blacksmith to work on grids, collet pegs, the light forged webs on the addition to the summerhouse, hooks and casement fasteners on the outer shutters, etc. With the exception of the wrought iron collet pegs on the surface of the façade that bore practically no traces of corrosion, the other Gothic and Renaissance ferrous elements were very stable with a uniform layer of surface corrosion. Part of the treatment of metal elements consisted in the conservation of the Gothic stained-glass window in the Rožmberk chapel and the repair of the vast modern stained-glass window built to add light in the Renaissance block at the

eastern side, close to the road approaching Horní hrad.

#### *Conservation of wooden elements*

All joiners' products: windows and blinds were repaired and treated with the maximum consideration. Great respect was also shown to the various types of windows of diverse age and origin. This considerate approach was not focused only on several very rare windows from the early Baroque period or many types dating from the 19th century. The same care was dispensed to the windows of more recent origin too. Practically all the windows have been preserved, including some that were quite seriously damaged. On the basis of detailed records and examination, the windows were repaired in a meticulous manner, dismantling the parts that could not be saved and renewing the coatings. During the repair works, the greatest care was taken to respect the preserved historic panes of glass, the forged elements and the original fastening systems, depending in each case on the situation. As part of the joinery work, shabby, badly-deteriorated double-hung Baroque window shutters were repaired and some of those missing on the top floor were replaced. The intervention included also the repair of the massive profiled cornice on the summerhouse roof, the conservation of the wooden ceiling with the central decorative motif in the summerhouse and the conservation of the partially bare half-timbered structure over the Rožmberk chapel.

#### *More urgent repairs of partial architectonic pieces: Consolidation of the late Gothic oriel window*

The more urgent repairs included the consolidation of three-dimensional architectonic motifs exposed to the weather and, therefore, more seriously damaged. A more detailed intervention was required, first of all, on the late Gothic oriel window supported by a set of vast joined stone corbels. Due to the exposure and its completely inaccessible position during its long existence, part of the original rendering was gradually lost and the joint between the masonry and the stone lining of richly profiled window portal had come loose. The condition of the fragments of decoration was so poor that after a short time it would not have

been possible to identify the original arrangement any more. After protecting the damaged brickwork by fixing the remains of the mediaeval rendering, the missing motif was completed by means of an exact reconstruction of the mortar frames with a bow-shaped frieze thanks to a careful survey of the preserved fragment. In a similar manner the side walls of the oriel window were repaired by completing the missing parts of the rough coat and smooth corner fitting at the place where the 1 window was attached to the consoles. After disassembling the metal sheets of the oriel window roof, an adjustment that originated in the nineteen seventies and showed aesthetical, technical and craftsmanly shortcomings, the original condition of the cover was identified, including the traces of burnt tiles under the window sill of the window above the oriel window. It enabled a credible reconstruction of the roofing, using identical material.

In a similar poor state of repair was the Baroque oriel window (outlet of the ventilation shaft), set on a pair of stone consoles to the west of the windows of the Rožmberk chapel. Within the framework of the stabilisation of the oriel window, its inside space was made accessible and cleaned, bare brickwork renders were completed and the small roof was refashioned with new hollow tiles. Also the crown of the walls protruding from the façade of St. George's chapel required repair. On the narrow belt of the bottom part of the façade, under the cornices of the pointed windows of the chapel, the decomposed fragment of the small skewed roof made up of several rows of thick plain tiles, probably dating from the Baroque period, was preserved. An essential part of the crown was already unprotected and the remaining parts were seriously decomposed. The loosened roof pieces were carefully removed, marked and classified and the small roof was renewed partly with original tiles and partly with new material.

#### *Stabilisation of the staircase buttress with a balcony*

The most serious damage was observed in the structure of the vertical mass of the staircase buttress, located at the front of the façade, made up of a balcony with a stone balustrade and supported above the



level of the main cornice by a console in the shape of a baldachin with a hipped roof. After a detailed inspection of the condition, a number of very serious defects and risk factors were found that caused concern about the dilapidation of the structure, because the peripheral walls of the prism are built, in the whole upper two floors, of bricks of only 15 cm bonded with lime mortar. The prismatoid buttress protruding from the rocky outcrop was built in the last decades of the 17th century on top of an older foundation. At the beginning of the 18th century the upper part of the buttress was resolved and completed with a prominent roof. The precarious situation required immediate reinforcement of the whole structure and temporary general rehabilitation of the whole upper part of the masonry of the buttress. Within the framework of the urgent repair works, the wooden structure of the balcony floor was examined, repaired and conserved without disassembling the stone floor and balustrade. The stability of the structure was strengthened by completing the existing tie beams with forged pegs on the façade. To contribute to the stability of the whole upper part of the buttress, the rotten window frames were replaced with copies of the original ones made of solid oak.

#### *Result of the conservation intervention*

After the integral intervention on the façade, the panoramic view of the castle is made up of the authentic mass and the entire original fabric that were created layer after layer over many centuries. It is necessary to stress that the largest share of the image of the façade with its impressive originality, diversity and noble age continues intact thanks to the ancient layers of rendering that were respected to the greatest possible extent during the repair works. In the future they will continue to be the unchanging and, therefore, completely authentic substance of the image of this exceptional monument. It must be stressed that, in connection with their consolidation with lime wash, the appearance of the original materials was left intact, even respecting localised abrasions on the surface, the complicated fragmental stratigraphy of the original surface treatments and, of course, the natural and nobly impressive patina. The structural, typological and chromatic

characteristics of the historic renders conserved in their aged state were considered untouchable and left unaltered. Changes were always related only to those parts where the original mass was no longer preserved or where it was completely inevitable, from a technological point of view, to perform a local repair intervention. The largest change in the overall panorama of the castle may be observed at the bottom of the wall of the façade, especially in the east. After the removal of the cement rendering in those parts, repairs were performed in keeping with the condition of the original renders in the immediate surroundings. In the upper part of these sections, the gaps in the renders were filled in and in the bottom sections and on the counterforts the fabric was stabilised with rough re-jointing of the stonework. If, in the case of solving a partial, minor repair to the surface of ancient, naturally aged historic renders it is logically necessary to limit the restorer's role to adapting the new material not to the original rendering as it was when freshly built but to the colours and shades of the now aged material, the approach to solving larger additions must be identical. By a cultivated processing of the new materials carried out on a large scale by the restorers, the additions were made to blend in with their historic rendering, paying special attention to the areas where the surface of the façade was connected to its rock base. A favourable aspect of the adjustment is the elimination of the hard lines of the horizontal boundary at the places where the cement rendering ended. In the overall view, obvious local damage is no longer very visible, because the places with decomposing bare brickwork on the oriel windows or on the surfaces of the façade were covered. The visual signs of tens of hundreds of minor defects were optically lessened (partial repairs of the renderings where material had come loose and mechanical interventions like the putting of cracks where there was a threat of water leaking in), and the negative consequences of lack of repairs due to the inaccessibility of the façade, were corrected e.g. by the removal of massive pollution due to bird droppings in some places, etc. The optical "solidification" of the overall expression of the façade was also

influenced by the conservation of the stone elements, the profiled window portals and the fine reinforcement of some of the strongly damaged rendering evident after repair. Repair of the roofing of oriel windows, the escarpment or the projecting sills in the eastern part of the façade by means of the renewal of their coverage with burnt or hollow tiles also contributed to the stabilisation and credibility of the monument's appearance. A not at all minor role for a visual "calming down" of the image of the monumental façade was also played by repairing the window panes and metal elements and completing the missing window blinds on the top floor in the original green.

The conservation of the southern façade of Horní hrad has provided a great deal of information, suggestions and important practical experience. The mere fact of making the façade accessible confirmed that the consolidation of the authentic façade was accomplished just in time, i.e. really at the very last moment in some places. Further postponement of the repair would undoubtedly have meant a marked deterioration of the physical condition, a speeding up of the loss of the original fabric and the risk of serious accidents. The use of traditional technologies and material simplifies maintenance and further conservation works in the future (maintenance of material compatibility and reversibility).

#### MANAGEMENT AND COSTS OF THE PROJECT

A very large team of workers from the National Institute for the Protection and Conservation of Monuments and Sites, architects and free lance artist-restorers participated in the preparation and accomplishment of the conservation of the southern façade of Horní hrad. The monument's conception was determined and monitored continuously by the guarantor appointed by the Pavel Jerie Institute (the National Institute for the Protection and Conservation of Monuments and Sites, with headquarters in Prague). The architects of the project studio GIRSA AT s.r.o., Václav Girsa and Miloslav Hanzl, processed the preliminary studies, revisions and completed the background materials, project documentation and provided professional supervision during the conservation

works. Dagmar Michoinová (Department of Technology of the National Institute for the Protection and Conservation of Monuments and Sites) was in charge of performing material research, drawing up the conservation methods and continuously checking the observance of technological processes. Experienced free lance artist-restorers cooperated with the team of specialists selected for conservation cooperated by performing the most delicate tasks. The building works were performed by the firm SD Hrad. An important role was played by the strictly observed repair method in the demanding task of restoring this building. The clarity and accuracy of the project handed in punctually and the responsible organisation and preparation made it possible to initiate the works at the very beginning of the building season, as soon as the climatic conditions permitted. The period during which most of the works were performed was the summer months and so in two years the essence of the work was successfully performed by the end of September. The responsible approach of all the participants and the strict observance of the time schedule contributed to the coordination of the conservation and other building works. Taking into account the climatic conditions and unexpected complications, regular on-site meetings were held and were of considerable importance for the result, because they always envisaged partial tasks for a short period. The accuracy of the operations performed and the logical sequence and continuity of activities were ensured by checking the works according as they were carried out. This clear arrangement enabled us to avoid taking doubtful measures or carrying out insufficiently well-thought-out interventions and contributed to the quality of the work. Complementary studies of normally inaccessible details of the fabric, carried out in parallel with the coordinated work of the team of free-lance restorers and the building firm, were well documented thanks to the unique unrepeatable opportunity to observe the monument so closely.

#### CONTRIBUTION TO THE FINISHED PROJECT

The stabilisation of the fabric and appearance of the southern façade of the

castle of Český Krumlov has preserved the great authenticity of an extraordinarily valuable monument, its genuineness and infinite communication ability with all its nuances. The extremely impressive, imposing picture of the site of Český Krumlov that survived aeons without detriment and, especially, the critical 20th century with its inconsiderate restoration works, was now preserved for the coming decades of the 21st century – with all the unique attributes of an authentic monument.

The completed works on the southern façade of Horní hrad of Český Krumlov represent one of the most extensive conservation interventions in the territory of the Czech Republic and provide valuable experience for tackling further rescue works in the area of the Český Krumlov state castle, especially, on the northern façade of Horní hrad, which are under process at present.

The experience of applying traditional conservation methods and materials was made use of subsequently in the repair and conservation of other important monuments, i.e. the medieval castles of Švihov, Rábí and Pernštejn.

Close contact with the naked façade provided a lot of remarkable and revealing information; the explorations enabled us to glean deeper knowledge of the monument and clear up a number of hitherto unknown chapters of its development. A great deal has been learned not only about the building process of Horní hrad, but also about the details of the methods and technology of the building activity performed on it over a five-hundred-year period.

During the conservation works organised on site a number of professional meetings on the subject of conservation of architecture were held with the participation mainly of professionals in heritage care, free-lance restorers, architects, technologists and representatives of building firms from all over the Czech Republic. The professional public was informed about the results of the conservation and the facts discovered at numerous lectures and in the professional press. The painstaking repair of the dominant façade of the castle area of Český Krumlov was followed with sincere interest by the general public, who hailed it with a very positive reception.

One of the three European Union Prizes for Cultural Heritage / Europa Nostra Awards 2008 in Category 1 – Conservation has been awarded to the conservation of the southern façade of Horní Hrad of the Český Krumlov State Castle. According to the Jury for Category 1 – Conservation, this project establishes new standards for Czech monument care and is appreciated as an excellent example of a respectful approach to conservation in Europe. The historic building's original fabric has been treated as an irreplaceable bearer of authenticity and an object of historic documentation. This approach transfers conservation ethics and methodology previously only used in the field of works of art to the scale of a whole façade and even to that of urban landscape in which the façade is a highly important element. The project has been realised using all possible means of preserving historical traces and the re-introduction of traditional artisan building skills and materials.



#### Javier Benlloch Marco, Manuel Jesús Ramírez Blanco, José Ferrandis Montesinos **STUDY, DIAGNOSIS AND CLEANING AND CONSOLIDATION PROJECT FOR THE QUART TOWERS**

##### *Historic background*

The Quart Gate –one of the twelve gates in the wall around Valencia –represents one of the major architectural exponents in Valencia of the 15th century, known as the city's "Golden Age". King Pedro the Ceremonious had the wall of which this portal forms part built after the outbreak of war between the crowns of Castile and Aragón. The urgency to protect the city from attack by Castilian troops obliged them to erect a wall quickly to enclose all the suburbs –mostly inhabited by craftsmen– the convents, and also part of the quarters of Jewish and Moorish citizens that had settled outside the 11th century Islamic city wall. Although there are documents that show the city planned to build a new one around 1321, and there were even some attempts to start it in the 1330s, the unfortunate circumstances of the century –plagues, famine...– made them postpone the works until the war of

the two Pedros became the catalyst that made the wall necessary.

This new wall was designed with twelve gates open towards the main ways into the city and with a typology characteristic of Aragonese architecture: the gate-tower. After the war, when things had got back to normal, around 1364, Valencia was still undergoing the exponential physical, demographic and economic growth based on trade that was to turn it into one of the most important cities in the western Mediterranean region (fig. 2).

In keeping with this up-and-coming development of the city, it was decided to monumentalise the wall built in such a hurry and rather haphazardly in the mid 14th century with architectonic elements that would in turn serve as a backcloth for municipal power, the image of the city and its defence. The construction of the new Serranos Gate between 1392 and 1398, instead of the old Roters Gate, as the main entrance to the city from Aragón and Catalonia, initiated and gave shape to this process (fig. 3).

At the turn of the 15th century, constant activity was begun to enhance the image of the city and its northern façade, looking on to the River Turia, and therefore also the most vulnerable part because of periodical flooding, received the city's best efforts.

In 1440 they decided to build a new portal to take the place of the old one, dating from 1356, at the crossroads of the Quart road on the western side of the city. The works began around 1441, but it was not until 1442 that they gathered the force that would last most of the twenty years it took to build it. After this gate, works would be performed on other less important ones, like the Nou Gate, and in the towers, like Santa Catalina Tower, and other elements in the walls.

Although in the centuries that followed the wall was a major element present in the city and interventions on it continued until it was demolished in 1865, in the late 15th century this "remonumentalisation" was considered completed as new Renaissance concepts of building and defence came into being and took force.

#### *The new Quart Gate. Genesis*

A great deal has been written about the authorship of the building, which has been attributed to several master builders from

the city. Names like Tomás Oller or Pere Bonfill have been the most popular, but if we review the work notebooks and analyse the stereotomy, it is more likely that the real artificers were Jaume Gallen and especially Francesc Baldomar. The former was responsible for the formwork and the latter for the stonework. Francesc Baldomar also made the singular design of the skewed floor plan the works for the new portal were practically finished around 1464, except for a few details and the actual hanging of the gates, which took several years more.

From then on, study of the history and uses of the gate –from the gunpowder magazine of the Kingdom, an arch of triumph to a women's prison and finally a military prison– reveals the episodes and vicissitudes that help understand the history of the city as a whole.

The analysis of the construction of the new Quart Gate cannot be made without referring to the Serranos Gate, the model for it. If Serranos was the natural way into the city for those coming from Aragón and Catalonia, Quart was the natural access for travellers from Castile, apart from the Sant Vicent Gate, another of the main entrances into the city from the south.

The prior construction of the Serranos Gate, with scenographic rather than defensive criteria, leads us to think that the same idea was behind the Quart Gate. The period of great building activity because of the economic growth in which the city and the kingdom were immersed, with the maritime expansion carried out by Alfonso III the Magnanimous –the most important made by the Crown of Aragón after the final conquest of Naples– put the city in a position to monumentalise another of its four main gateways, in this case the entrance from Castile.

Under those circumstances, the construction of the new Quart Gate instead of the previous one, probably erected, like most of the gates, in 1356 in the shape of a cube or gate-tower. No documents regarding its original physiognomy have been found, since the first topographic plans are by Mancelli (1608) and the first known engraving by Wyngaerde (1563) and in both of these the new gate can be seen. Written documents describing its appearance have not been found either.

As regards its construction, it is curious to note the skewed layout of its floor plan, as

on one side it respects the design of the wall and on the other its obliquity as regards the road to Quart (fig. 4).

In 1943 Carreres Zacarés provided the first known documentary news of the intention or beginning, affirming that Carboneres took "from a book of by-laws about walls and fences, where it says that in March 1442 the jurymen and workers agreed that in addition to the thousand florins to be spent each year on the works of the said gate, a thousand more was assigned they were finished". This quotation leads us to believe that that year the decision was taken and the works were ordered to begin. But by studying other documentation, after specifying a relative chronology, more was discovered and verified about the actual initiation of the works.

The absence of the books of the walls and fences series for the years 1441 and 1442 (from March to March) prevents us from knowing the exact date the building started and the first payments and works.

This circumstance led us to us consult the council manuals for those years. Throughout 1441 no reference whatsoever is made to the Quart Gate, but in 1442, an entry dated 22nd April states that the following works are being carried out in Valencia: Serranos Gate (some refurbishment), the dockyards, the consulate, the fountain in the Grao and the golden hall of city hall. That is to say, there is no reference to the Quart Gate or any other.

Continuing with the investigation into that same year, we find the first reference to the gate on 22nd August 1442, which says: "...from now on, as long as the works being performed on the Quart Gate last, may no person of whatever religion, condition or social class dare to bring lime into the city by any other than the Quart Gate," which makes us presume that the works began on some date between April and August 1442.

On the other hand, and going back to the books of by-laws about walls and fences, where all the payments made and works performed are recorded, the first reference to the Quart Gate found dates from March 1443 –the date on which these books started– and states as follows: "Friday, 9th March 1443. On this day no works were carried out because of rain, and as supervised by the honourable jurymen –representatives of the city– workers and

Racional –the city lawyer– to resume the work on the Quart Gate after the supervision of the last day.”

From this we can deduce that the foundations were laid in March 1443 and that, after the rain, the works were ordered to continue. From then on, the documents provide an exhaustive list of the day-by-day payments for the works without any remarkable interruptions, and explain that the formwork of the bevel, the base of the monument, is being made (fig. 5).

#### *History of the monument until the 20th century interventions*

The monument comprising the gate and towers were absolutely unrecognisable as regards the original building, due to the improper use carried out for centuries.

In this respect, Escolano spoke about a fire in the City Hall in 1585, which made it necessary to move the prisoners to other places in the city. In the same sense, J. Teixidor mentioned a quotation written by March telling the place and date of the fire: “On 15th February, a Saturday, at seven o’clock in the evening, Our Lord permitted fire to break out in the Archivo de Racionalado in the city...”

The same sources state that the fire affected the prisons quite badly, and there was nowhere to house the prisoners. For that reason the city judges set nearly all the prisoners free, with the exception of “...a few of those that were hardened criminals were taken to the Tower of the Quart Gate.”

Another use of the Quart Towers a prison for women in the year 1650 is also recorded. “...they were used as a prison for lascivious women, and his holiness the bishop of this city, Don Fray Pedro de Urbina, provided funds of his own to habilitate the premises and feed the prisoners.”

They were then used as a military prison and, although in the year 1932 a law sanctioned by the Constitutional Courts of Spain demanded that the army return the monument to the city, the Spanish Civil War was probably the reason it was not returned to Valencia Council until 1944.

#### FIRST RESTORATION INTERVENTIONS (20th CENTURY)

##### *Carlos Soler’s intervention*

The municipal architect Carlos Soler designed and carried out the first

important intervention, which took place in December 1959. Soler presented a restoration proposal that included the installation of a lithological museum inside the towers. It was a clever idea because it meant giving the towers suitable use to justify the necessary and urgent restoration and at the same time eliminated all traces of the prison and opened the interior platforms towards the city, enclosing them behind wrought iron railings.

Soler started the memorandum of the project by stating his intentions: “The aim of the project commissioned is to rehabilitate the Quart Towers by restoring this architectonic monument to its original purity...”. And so it was, because the scope of the intervention involved the demolition of a building that had been added on to the northern tower (looking on to what is today the Palleter garden) and opening up the above mentioned rostrums towards Saint Ursula Square, removing a false intermediate frame on the first floor of the northern tower and inadequate inner staircases, etc.

During the works, Carlos Soler rounded off his proposal by opening the entrance into the northern tower (later consolidated by the architect Emilio Rieta) and building a garden instead of the prison courtyard beside the wall (figs. 6 & 7).

##### *Emilio Rieta’s intervention*

Emilio Rieta substituted Soler in 1966 and as municipal architect in charge of municipal monuments carried out most of the work on the Quart Gate and Towers, revising and improving Soler’s ideas with a project entitled “Northern tower stonework. Garden and Wall”.

In 1972 he proposed a “Project for the Partial Reconstruction of the Quart Towers to be Opened to the Public, which he improved in 1975 ” with the “Project for the Total Reconstruction of the Quart Towers and Ironware Museum” which involved more intense and committed works, endowing the monument with services, restoring roofs and adding winding stairs, a large staircase leading from outside to the first floor, a neo-Gothic staircase leading to the second floor and a large railing surrounding the large staircase on the ground floor. All historic falsehoods, no doubt, on a preexisting building with numerous

mutilations, but carried out nonetheless with great sensibility and respect for the monument.

We must insist on the advantageous side of these two interventions, which meant that the monument was kept in a good state, albeit without a definite use, with an image quite similar to what the Quart Gate must have been like. After Rieta’s interventions, the Council had several works carried out in the eighties and nineties, all minor maintenance works and some very questionable cleaning works: if we examine the cleaning criterion put into practice on the inner side (giving on to Santa Úrsula Square), we will see the evident erosion on the ashlar fabric with the ensuing loss of the old reddish lime shade.

#### THE CURRENT INTERVENTION

##### *Prior operations*

The intervention for the “Study, diagnosis and cleaning and consolidation project for the Quart Towers and Gate” was carried out thanks to a collaboration agreement between Valencia Council and the Polytechnic University of Valencia. The examination of the history of the monument and its insides conditioned the criteria of our intervention: conserve and consolidate; for any other alternative would have involved the risk, among others, of losing cultural layers, such as the damaged and loosened cladding of the exterior façades (with numerous traces of past conflagrations and the passage of time) (fig. 9).

It is obvious that the beginning of every action requires a preliminary study to be prepared in order to get to know the monument and its state of conservation. We are aware of the limitations of a preliminary study that is not complemented with an integral cleaning intervention, since dirt disguises lesions and cultural layers that cannot be detected in these preliminary studies as a general rule.

This was our ethical stance regarding the monument: in the first place, it needed to be exhaustively documented, and then all the investigations had to be performed, in situ tests and essays required knowing really well the state of affairs. To that end, we were guided by another basic principle that we feel should always be taken into account on interventions on heritage: the



design of a suitable interdisciplinary team. It was a case, then, of gathering together all the sensibilities of each team member with one aim in mind: to recuperate heritage and learn more about it at the same time in order to put it at the service of the Valencian society –who is paying for the works –and of future researchers and people in charge of carrying out new works.

#### *The work*

The project, as a vertebrating axis, required the different functions and the work protocol to be divided out in the very likely event of there appearing elements or layers of heritage value (above all during the early cleaning stages, for the reasons mentioned above). This circumstance demanded very close coordination in the interdisciplinary group so as to operate in the most reliable way possible. And that is how during the works a lot of old graffiti was found (fig. 10), fragments of Gothic letters (on the commemorative plaque), rifle bullets and cannonballs (still lodged in the walls) (figs. 11a & 11b), vaulted niches, traces of the prison period and remains of the original colour in the cladding inside the towers. These clues helped us get close to the original image of the Quart Gates, with its ashlar fabric coloured by reddish lime wash and aerial lime cladding, inside and out, all in the same shade.

The works began with cleaning (with the relevant in situ tests) and, in view of the results that were more efficient and respectful of the façades and ornamental elements, once the dirt had been removed, we proceeded to take decisions regarding the wisdom of consolidating or repriming elements depending on their degree of deterioration. In this respect, the positive results of an examination and structural study of the pieces with a load-bearing function (for example, two corbels on the southern tower and the main arch of the gate) permitted us to remain faithful to the general criterion of the intervention: conservation. And so we proceeded to act with each and every one of the damaged elements, leaving repriming as a last resort.

This conservationist criterion permitted us to achieve an enhanced final image of the monument, maintaining the traces of the cannon shot from the Wars of Succession,

Independence, the cantonal uprisings, etc. as a testimony of the history and strength of its good fabrics and at the same time, these traces have become an important source of information for future researchers, specialists in monument restoration and new interventions.

In the same way, we had the opportunity to consolidate elements with a certain degree of structural risk; replace –partially or totally– ashlars with missing pieces (figs. 12a & 12b); repair installations that caused leaks and serious lesions on the roofs; rising damp inside the towers; e;removal of biodeterioration; and the installation of protection systems against birds, taking into account the serious damage they had caused, especially in the interior of the putlog holes used to build the towers.

#### INTERVENTION TECHNIQUES

##### *Rammed earth work on the towers*

This is a very wall typology because, although its building method was that of rammed earth walls (rammed earth in recoverable formwork), Master Builder Baldomar used mortar of lime hydroxide and aggregate of different-sized pebbles. The design of the towers is straight at the sides and curved at the front, with a (quite considerable) consistent thickness that reaches 3.5 m from the bordure level of the ashlars in the ground floor to the spring of the crowning machiolation. These walls rest on a sloping filling of lime mortar and larger stones that form the foundation-bevel of the towers. Another unusual feature of the building system was the use of “climbing” scaffoldings, as can be seen from the putlog holes found in the extrados of the towers, which go through the walls and served to put through timber girders where the whole structural system of the recoverable formwork must have been laid. Such techniques were incidentally taken from the rammed earth method. The finish of the fabric consisted in a lime hydroxide mortar cladding with a good selection of fine sands that gave it an appearance of lime wash.

During the works we verified the good state of repair of the fabric, which we attributed to Master Builder Baldomar’s knowledge of defensive architecture and his dominion of his trade, because apart from the lack of structural deficiencies we

must emphasise its functional adequacy. In this sense we were able to verify that the impact of 329 80-calibre cannonballs and a large number of rifle bullets and shrapnel had not affected its stability.

##### *Ashlar fabric*

The ashlar fabric is located in the body of the portal; the intrados walls, stairs, arches over doors and ribbed arches on the floors of the towers and in the machiolation and the parapet walk. That is, in all the spaces and building elements that require better fabrics either for the appearance (as is the case of the portal) or for constructive reasons: the finish of corners, lintels, steps, battlements, etc., where a less “solid” fabric would not be the best way to solve the problem of stability and finesse.

A lithographic study of the monument determined that the stone was lime which, to judge from its characteristics very similar to those of the Lonja de Valencia, was taken from a quarry in Godella; this quarry was used to provide stone for a large number of buildings in the city in the 15th century.

As regards the works, the criterion followed was to prioritise conservation and consolidation over repriming; the intention was to leave visible the traces of siege –and improper use– suffered by the monument, which, apart from reliably reflecting historic events, are a token of the solidity of the building. So, once the degree of stability of the damaged constructive elements had been verified, we proceeded to weigh the possibility of conserving or consolidating, always choosing conservation whenever possible.

In general the intervention on the stone fabric brought with it more than one surprise –because of its nature of clad fabric– since despite the excellent condition of the ashlar fabric in the arches and vertical walls of the gate, it was conceived as a work to clad or tint, for so we discovered during the cleaning and restoration process of one of the most beautiful fabrics in the monument: the ribbed vaults on the first floor (fig. 15), where on the appearance of numerous projections and other stonecutting flaws false ashlars are painted on thin layers of cladding and protective lime wash (fig. 16). We insisted, therefore, on giving prevalence to the ethical criterion that

served as a referent in the intervention over the method and techniques, since we believe these are the crucial factors in obtaining success. The intention was to use a technique that would not damage the cultural aspects, which we put before the stone itself: colour, cladding and old graffiti and, where there were none, to prevent the stone from eroding (fig. 16). So after several tests performed in situ, the following technique was applied:

In places with polychrome or graffiti of historic value, preliminary consolidation was carried out with acrylic resin Paraloid B-72 (98% acetone and 2% Paraloid). On the surfaces with salts and efflorescence, Arbocel compresses, made of cellulose paste and distilled water, were applied. These were protected with sealed plastic sheets, which were left for 10 days and submitted to quality control twice a day. The polychrome walls of great historic value were protected with sepiolite or cellulose compresses covered with polyethylene.

Once the cultural supports of heritage value had been safeguarded, we proceeded to clean the stone by using a system we had tried out before and found successful on the cleaning of the Lonja in Valencia: jets of aluminium silicate (with sizes that should not exceed 0,09 to 0,25 $\mu$ ) and with very well controlled pressure of 1 kg/cm<sup>2</sup>; with the exception of the very dirty areas and places with a crust, where the maximum pressure applied was 2 kg/cm<sup>2</sup>. In any case, the quality control of the material (figs. 17, 18 & 19) and labour was constantly carried out by specialists. The final treatment consisted in a general waterproofing process, previously tested in situ, with silicones in an aqueous solution, silicones in dissolution with an organic solvent and metallic soaps (aluminium or calcium zinc stearate) the product that turned out to work best in this case was a combination of silicones in an aqueous solution, as a higher degree of resistance to rainwater was achieved while conserving the transpiration of damp from inside the fabrics (fig. 20).

#### *Timber*

Although there is not very much of this material present and, above all, with the exception of the main doorway, it is not very old, the treatment applied was the same as for any other piece with a great

heritage value. The intervention began with a stripping process with methylene chloride, followed by sandpapering. In some cases compresses with water, ethyl alcohol (50%) or oxalic acid (5%) were used. A technique with acceptable results when applied to the doors on the ground floor of both towers (dirty and covered in thick coats of inappropriate paint and varnish) was a jet of aluminium silicate abrasive at very low pressure (0,5 kg/cm<sup>2</sup>) (fig. 21).

#### *Railings and metal fittings*

Except for some of the metal fittings on the door, the railings are all recent (almost all of them dating from the intervention by the architect Emilio Rieta). In any case, the cleaning was started by stripping the varnishes with fine aluminium scourers and steel wool steeped in acetone grease removers. Then several tests were carried out with different rust conversion products (Hammerite and Turco). The latter was used because it is matt. Two coats were applied (figs. 22 & 23).

#### *Biodeterioration removal*

After an exhaustive study of the damages caused to the monument by different biotic agents, birds among others, the team of physico-chemical specialists took many samples and carried out many laboratory tests to determine the most suitable solutions for each case. In this sense, one of the most important lesions was caused by the presence of a large number of birds, which settled there and, worse still, built their nests on the monument.

An adequate study of the situation (since we could not avoid their presence) made us decide to stop them settling and building their nests there. For that purpose, we proceeded to fill in partially the plug holes that were used to build the towers. In fact some of them had already been filled in with solid brick fabric (fig. 24). So the intention was not to conceal them but rather to make them stand out (in keeping with general conservation criteria), but the birds had to be prevented from building nests. Each plug hole, open and unprotected, was over 3 metres deep and whole families of birds, nests and even skeletons were found in them, turning the interior of the walls of the tower into a real cesspit.

As regards biodeterioration caused by organic matter: lichen, moss, plants, etc,

steps were taken to apply treatments at the very start of the works in order to find out how effective they were over the largest possible time span. The relative efficacy of some products led us to choose a product with 50% aqueous solution. We found Tordón produced acceptable results (at least for as long as the works lasted –over a year).

#### *Cladding and paint*

This was undoubtedly one of the most delicate matters and therefore the greatest challenge. It was important to avoid covering the existing intrados of the towers, which would have gone against conservation criteria, apart from removing the mark of cannonballs, gaps and traces of past uses, which would have meant losing a great source of communication and information between the monument and visitors.

But on the intrados of the towers the problem was more serious, since the presence of inappropriate cladding with Portland cement had provoked a great deal of efflorescence because it prevented the lime fabric from transpiring. So the original old Puerta de la Cal (Lime Door) was covered in the wrong material.

The final solution was easy to adopt, because the grey cladding had to be removed for two reasons: first, the need to restore to the fabrics the correct transpiration and eliminate the damp; and, second, to eliminate the grey that was totally out of keeping with the patinas on the few remains of the wall and the exterior of the towers still in existence.

We suspected the colour the interior of the towers must have been originally (taking into account the exterior cladding), but since we were not certain as there were no traces of the original colour, we decided that the white of aerial lime (which was present in the whole Portal de la Cal) would be better than the current grey. It would be a sort of tribute to that doorway. However, during the development of the works to remove the wrong cladding in the southern tower and to a lesser extent in the northern tower remains of the original aerial lime mortar cladding were found and, much more importantly, traces of old paint that, after numerous physico-chemical and colorimetric tests, was the same as that found on the exterior of the towers and the wall.

Thus the dilemma was solved. All that remained was to construct and execute the works according to old techniques: lime cladding by the day and applying the lime wash by hand performing tests with the colorimeter to make it match the samples found in situ. The final colour was made by mixing yellow and red in a 40-60 proportion (figs. 25 & 26).

Regarding the exterior cladding, in some cases it had come almost completely loose, so that prior consolidation work was required by gravity injections of old lime mortar (over 15 years old) and in some cases with calcite of the same lime mortar. On more than one occasion it was necessary to use Japan paper, polystyrene sheets with compreg wood panels as protection later subjected to pressure for several weeks until it consolidated. Once the precarious old cladding had been consolidated, several cleaning tests were performed with lime wash and eventually the least aggressive and most suitable of these was used. Deionised water was mixed with a small amount of lime wash and marble micro-powder and rubbed on by hand in several sequences and finally washed and rinsed with a small amount of deionised water.

#### FINAL RESULT

The major motivation behind our intervention was the wish to leave the history of the monument clear for all to see, conserve it and consolidate it if necessary. But this constant idea of conserving demanded a single criterion to save us from contradictions. It was a matter of consolidating the elements in danger of coming loose and guaranteeing the original form of the elements that were missing (as was the case of the interior cladding of the towers), although the budget and, above all, the requirements of the commission led to apparent contradiction since they involved cladding the vaults of the lower floors of the towers but not the top ones.

As regards the exterior, the poor condition of the cladding, in the process of falling off, full of bullet holes and nonetheless one of the marks of identity of the towers of the monument is, in our opinion, a clear case of this stance; for like the stones missing on two modillions on the machicolation of the southern tower and the central voussoirs of the main arch in the

gateway, they have been consolidated and conserved in their current state, on finding there was no structural risk in the case of the latter.



#### Ilaria Cavaggioni & Alberto Lionello THE FRARI BELL TOWER IN VENICE: STUDY & RESTORATION

The architectonic complex of the Basilica of Santa Maria Gloriosa dei Frari in Venice with San Pietro chapel and the bell tower in its present configuration is the result of a building process that began in the mid 14th century, with the reconstruction of the Franciscan church and, twenty years later, the construction of the bell tower (fig. 1). The direct reading of the architectonic fabrics, the stratigraphic-constructive study and the historical and documentary analysis have made it possible to identify three building stages from a stratigraphic point of view, although they only partially belong to different chronological works.

The first phase, which lasted from 1361 to 1396, corresponds to the construction of the bell tower in an internal and external double-fust structural fabric with a base of Istria stone and a construction of perimetric ramps to give access to the bells. The bell tower was added to the already existing Franciscan Friars Minor church built in the mid 13th century, whose orientation was the opposite of the current one. However, at least during the initial building phase, consisting in the base made of Istria stone, it was conceived as a free-standing architectonic element, completely detached from other constructions.

The second building phase, which took place between 1340 and 1432, consisted in the reconstruction of the church in its present form, partially incorporating the bell tower beside the transept of the new church. The vertical walls of the church and the bell tower were completely separate from each other to permit differential movements between the two constructions so different from each other as regards mass and size. The only link between the two bodies of fabric was at the height of the brick vaults of the transept and the nave on the left hand side, which lean directly on the bell tower wall.

The third building phase, provisionally attributed to the first half of the 15th century, consisted in the erection of St Peter's Chapel in 1432 at the south east corner, between the wall of the bell tower and the church, with fabrics resting on top of already existing constructions.

Although these three structures were built very closely to each other in time, they were conceived as autonomous constructive units (fig. 2).

In September 2000, the cracks in the vaults and the lateral nave of St Peter's Chapel grew worse and some fragments of rendering and brick came loose were a sign that there were active structural mechanisms affecting the parts attached to the bell tower (fig. 3). For that reason, the Sopintendenza per I Beni Architettonici of Venice performed emergency repairs to prop and secure the damaged parts. These emergency works afforded the opportunity to initiate a systematic survey of the fabric. Research was carried out to discover, by means of several analyses, the building phases and transformation of this historic building that could have altered its structural behaviour over the years, understand the active mechanisms and thus define a monitoring project that would provide important information regarding the speed of the deterioration. Rather than representing a propaedeutic introductory phase of the restoration project, the analytic, cognitive approach of the preliminary study constituted the basis of a methodological procedure that initially provided guidelines for the project decisions and later for the actual works by means of an ongoing reference and feedback process that compared the analytic details with the real facts. It was therefore deemed crucial to consult all the historic and recent documentation about the bell tower.

At the same time as the historic research, a series of instrumental surveys were performed to compare with the data yielded in prior study campaigns. In the first phase, it was considered wiser to approach the problem on the basis of the numeric detail taken not so much as an exact quantitative datum as a qualitative element indicative of the tendency of a mechanism in action. For this reason, the level dimensions of the 1942 study on 48 points of the stone in the interior and exterior of the basilica were corroborated.

The church's structure was found to have subsided between 1 and 2 centimetres, while the belfry and the near it had subsided more, as shown below:

East corner: -4.98 cm  
 South corner: -6.13 cm  
 West corner: -9.33 cm

The verticality of the bell tower was verified with the photographic maps drawn up in 1990 by comparing the height of certain points of the tower. An average westward displacement of 2 centimetres was found in the shaft of the tower at 45 metres from the ground in the opposite direction from the existing inclination of the belfry towards the square. This was an anomalous behaviour of the tower's structure which, contrary to what usually happens, tended to return to its vertical position in the top section.

An in-depth examination of the documentary research carried out between 2000 and 2001 and comparison of the historic information available with the material data that could be seen in the fabric made it possible to verify the initial building phases and the successive restorations works that could have produced constructive alterations with the ensuing modification of its structural behaviour. The documents in the archives permitted a rough reconstruction of the three important restorations that took place between the second half of the 19th century and the first decade of the 20th that seriously influenced the belfry and the adjacent San Pedro chapel.

The first documented intervention on the bell tower was performed between 1862 and 1866. The initial project included "Repair and renovation works on the external wall around the belfry". A drawing of the east wall of the chapel made in 1862 shows the settlement of the section of the wall in contact with the belfry, badly damaged as a result of the collapse of the enormous mass of the wall of the tower, although the two structures were entirely independent (fig. 4). The project involved the demolition of the whole part of the wall affected by the subsidence, with a width of 2.7 metres, and its reconstruction with a window the same shape and size as the existing ones in the same drawing instead of two plain rectangular openings and a geminated window of small dimensions.

In 1864, during an excavation performed

to 2.4 metres below street level, the old foundations of the wall of San Pedro chapel adjacent to the belfry were found. These foundations were made of masonry and largely disjointed due to the loss of mortar and the presence of scantily resistant muddy subsoil in the joints. Instead of the new foundations for the section that was to be reconstructed provided for in the project, it was decided to build a robust load-reducing arch with a wall of a foot and a half with one side resting on the socle of the belfry foundation and the other on the foundation of the chapel. So an initial link was built between the two buildings at foundation level, with the ensuing alteration of the structural behaviour of the belfry-chapel ensemble.

But the movements of the belfry eventually affected the interior of the church, where there was another structural connection between the two blocks of fabric at the height of the vaults. A prop was placed at the level of the first arch in the nave on the left side, resting on a pillar built into the belfry wall, and scaffolding was erected to verify the damage in the badly damaged stone archivolt that had come loose, with large pieces in danger of collapse, and examine the large lesion at the top of the wall. A drawing dating from 1867 illustrates very clearly the damage caused by the bell tower with the representation of the map of the cracks in the transept wall at the height of the first arch of the left nave. It is especially useful to compare the 1967 drawing and the current cracks in the southeast part of the belfry (fig. 3). In 1867 the wall over the arch connecting the basilica with the belfry was damaged due to the different incompatible subsidence rate of both structures.

The second restoration works were performed between 1867 and 1873. This was the "Radical project for the restoration of the roof of Santa Maria Gloriosa del Frari and other urgent works in the interior of the same church", which, in general terms, proposed three interventions: the reconstruction of the whole roof of San Pedro chapel, the dismantling and reconstruction of the stone arch in the left nave adjacent to the bell tower and the demolition and reconstruction of the brick vaults of San Pedro chapel. The project contemplated

the building of a relieving arch the same thickness as the wall just over the stone arch of the lateral nave, which was completely deformed because of the differential settlement of the piers and, as a result, the dismantling of the archivolt with the restoration, the inlay of the stone voussoirs and the replacement of the elements that could not be saved. Direct examination of the architectonic and constructive elements together with the performance of some stratigraphic analyses at certain spots, in an attempt to locate important traces that would reveal the interventions carried out made it possible to clear up some essential points. The stone voussoirs were dismantled and mostly replaced by new elements. The different degrees of degradation and surface elaboration were quite evident. It is unlikely that the relieving arch was built the same thickness as the wall just over the stone arch, since traces of this intervention cannot be seen today on the inner wall, free from plaster and rendering.

In a word, the intervention on the stone arch intended to erase the effects of degradation but did not attack the cause of it. After the work was finished, the sinking of the belfry had not been checked and today the subsidence can be seen in the vaults of the nave adjacent to the tower and in the stone arch where the movements are registered. The semi-arch beside the belfry has almost completely lost its geometry and there are serious gaps at the pressure curve in the middle third of the section (fig. 5) and shifting of the voussoirs of the keystone with cracks in the joints measuring as much as 1.5 centimetres (fig. 6). The settlement of the belfry had caused such important damage in the brick vaults of the adjacent Saint Peter's Church that it had been necessary to demolish them and build new vaults supported with a cane frame treated with three coats of linseed oil imitating stone. The intervention was limited to the central Gothic fan vault since the segments in the presbytery area were repaired by means of partial substitution only on the unconnected ceramic voussoirs in the ribs. In 1902 the collapse of the San Marco bell tower stirred up once again a great deal of long-standing concern about Venetian belfries, and the Frari belfry was not exempt from these preoccupations. "So,



since the day of the Titanic collapse, some people had the dreadful sensation that everything was going to collapse [...] from the Procuratie Vecchie to [...] the Frari belfry [...].”

The subsidence of the foundations of the belfry, with a differential fall of almost 30 centimetres in relation to the church registered at the beginning of the 20th century and the subsequent inclination towards the south that in 1904 measured 76.5 centimetres on a height of 42.5 metres, had caused serious damage both to Saint Peter’s Church and to the vaults of the left nave of the church, which required consolidation works on the walls and the foundations (fig. 5).

The tests carried out on the foundations revealed that the base supporting the foundations was insufficient for the size of the belfry, which was the main cause of the subsidence of the tower. For this reason, consolidation works were started on the foundations of the belfry by widening them, beginning on the south where the greatest inclination existed. Abundant documentation in the archives with many drawings, photographs and maps of the work made it possible to reconstruct fairly accurately the nature and importance of the works performed at the different stages. The work was made by means of counterforts that started in the southeast angle and the front area of the unloading arch at foundation level between the wall of Saint Peter’s Church and the belfry built in 1864. At the foot of the old boarding at the base of the belfry a 380 x 20 x 20 fence of maple trunks was built with a 3 metre platform parallel to the foundations of the belfry 2 metres away from the traditional boarding, and after chipping the ashlar in the foundation of the belfry, tiered carving of the vertical surfaces and, spreading a thick coat of rendering on top to increase the adhesion of these ashlar, several layers of underpinning concrete an average 15 cm thick were poured (fig. 6).

In December 1904 works were also carried out on the walls of the belfry, which consisted in piercing holes to insert metal trusses inside them. The report entitled “Consolidation and restoration works on the church, belfry and sacristy of Santa Maria Gloriosa dei Frari in Venice”, dated January 1904, describing the project for the consolidation of the foundations of

the belfry, reveals that these works should also have been performed on the internal walls of the church. However, the works on the outside of the walls were deemed more urgent and were given priority, and the interior walls were never consolidated. In Saint Peter’s Chapel the reinforced groined vaults made in 1867 were demolished and replaced by vaults of perforated brick 10 cm thick rendered with mixed mortar with an 8-10 cm layer of cement applied on the extrados of the vault.

If the 19th century interventions had striven to lessen albeit not to eliminate the visible effects of the degradation by acting on the fabrics that had indirectly been affected by the structural problems of the belfry, the works performed in the early 20th century directly attacked the causes with a view to solving the origin of the problem.

In the year 2000, an analysis of the relative subsidence between the belfry and the basilica since it was built until 1902 and from 1904 until the present day (fig. 7) revealed that the intention of consolidation, apart from modifying the direction of the inclination of the upper part of the tower, had considerably linked the structure of the belfry with the basilica and Saint Peter’s Church by means of the connection systems performed on them. As a result, part of the loads of the belfry were transferred to the adjacent foundations, reducing the degree of subsidence but affecting part of the basilica also.

After almost a year’s monitoring by high-precision levelling, the belfry was found to have sunk more than the structure of the basilica and this settlement was not uniform, but greater at the internal angle towards the apse (1.3 millimetres). From the information and the results obtained, it was calculated that the subsidence, deformations, lesions and increase in compression at some places in the structural elements, particularly in the buttress at the corner, could not be solved with repairs but their causes should be eliminated completely (fig. 8).

The problem was very complex because of the interrelationship between the structures of the belfry, the basilica and Saint Peter’s Church, conceived as independent and later attached to each other, as was discovered from a direct reading of the

fabrics, compared with the data found in the historical investigation of the archives. Besides, there was a close relationship between the structural and geotechnical aspects: in order to guarantee the conservation of the belfry and basilica ensemble, it was necessary to find a suitable technological solution that would permit a gradual intervention and facilitate control of the effects during the whole works.

For these reasons, an interdisciplinary work group was set up, comprising many professionals and scientists from different fields who shared knowledge and enriched each other in the task of conserving and consolidating the architectonic ensemble guaranteeing the efficacy of the intervention and respect for the monument’s integrity at the same time. In the analysis of the foundation structures, it was crucial to have prior familiarity with its constructive characteristics and the modifications practised during the different restoration works in order to compare them with the study of the deformations and the map of cracks both in their historical evolution and in real time. Contrary to what usually occurs, it was considered particularly necessary to delve deeply into what was not readily visible and deducible because it was below ground level to discover the geometry, materials, deformations and mechanical characteristics of the foundations and the composition of the soil.

The verification of the stratigraphic profile and the physico-mechanical features of the soil and the composition and state of conservation of the foundations required an extensive geognostical campaign based on vertical and inclined probes and penetration and dissipation tests. The results of these studies confirmed the geometry and composition of the foundations as they were described in the historical documents and yielded information about the characteristics of the soil and, in particular, the layers of clay that were responsible for the most serious subsidence.

The survey and studies performed on the subsoil were compared with the documents in the archive of the works carried out in the early nineteenth century (fig. 9), and showed that the foundations of the belfry had been built with perfect

constructive geometry according to the rules of Venetian tradition: a wooden fence stuck into the ground comprising trunks with an average diameter of 20 cm and whose length varied between 1.5 and 2.5 metres, a horizontal platform of crossed planks and the foundations proper, made out of blocks of Istria stone.

The comparison of the hypothetic configuration based on the documentary sources with the result of the geognostic campaigns led to the construction of a reference section that permitted a cross-verification of the data and confirm both its geometry and dimension and the materials employed (tiers of Istria stone to a depth of almost three metres, boarded with timber and wooden piles to a depth of about six metres (fig. 10). The complex historical reconstruction of the consolidation system documented at the beginning of the 20th century was also confirmed. This comparison also made it possible to deduce a difference in material between the foundation of the tower and Saint Peter's Church, where another type of stone was used, sandstone and poorer quality white stone.

The constructive process and the transformation of the base and foundation were also subjected to a comparative study, which consisted in direct observation of a geometric nature with material and stratigraphic surveys and information indirectly gleaned.

The foundation of the Frari belfry is made of a fabric of stone ashlar forming a tiered socle formed from ashlar between 37 and 38 cm high and about 30 cm thick, with smaller bondstones (20 – 35 cm), which serve to connect it with the foundation wall. The corners with the headers and stretchers of the ashlar placed alternatively give greater stability to the bond along the arrises of the tower, while the decorative bands have a different solution at the corners, where they are simply placed at an angle of 45°. The stratigraphic-constructive examination of the foundations took into account the nature of the works, characterised by their material homogeneity, their lack of plaster and rendering, very thin joints and the type of transformations brought about basically from the substitution of individual ashlar rather than explicit breakages, which can be recognised thanks to the difference in surface or the

mortar used for bonding. For that reason, the reading system was based on the traces left in the different treatment of the stone (fig. 11), and the stratigraphic analysis was focused mainly on the joints, a sort of "microstratigraphy", where the mortars used for bonding and repointing provided the principal way of distinguishing between the different layers.

The superficial features of the different types of carving on the ashlar made it possible to identify the original parts, characterised by a systematic difference in the carving method –by the alternation of smooth elements and parts fashioned with a marteline– which establishes a hierarchy of treatment in which the carving helps identify the functional parts (structural elements, cornices and tori, rendering, decoration). The different colour and size and parameters like the regularity of the marteline marks and the height of the torus imitating the original ones makes it possible to distinguish the elements inserted in the successive replacements. And in particular, the ashlar inserted from the 19th century can be distinguished thanks to the use of the bush hammer. Microstratigraphy of the joints revealed that the mortar used to place the original foundations was ivory-coloured, homogenous and friable, while the mortar in the joints of the pilaster and walls of the church is a paler shade, homogenous, with whitish marble dust with a few little pebbles. A whitish colour and sandy consistency identify the areas repointed at a later date.

The creation of the basilica involved raising the level of the visible pavement in the northeast corner, where there is a pillar formed by a group of little columns that belong to the church. By observing the border it was found that the pieces of the corner of the tower over the pavement level were scaled down to facilitate bonding with the pillar of the church; on the contrary, the pieces below pavement level were inserted whole, eliminating the two ashlar at the corner of the tower and adapting the dimensions of the plinth to the perforation made to lay it. The shape of the ashlar extracted would explain the asymmetry of the plinth of the pillar. In the west side, the stratigraphic connection between the pillar of the church and the corner of the tower has a different type of bonding system, made by alternating the

ashlar of the pillar inserted after extracting the ones from the tower or by breakages performed at the corners of the belfry in order to join the two stratified walls together more efficiently (fig. 12). At the top of the foundations, the initial wall is built of dark red bricks, blackened on the surface, with signs of having been treated with quicklime and had a red finish applied, still visible on the outside. The bonding that characterises the old parts of the brick wall and also present in the initial parts of the corners is homogeneous and consistent, ivory-coloured and shows traces of having been incised. Some traces of mimetic reconstruction of the brick wall can be seen, although the grouting has a reddish surface finish because the colour of the more recent bricks is somewhere between reddish pink and yellow with greyish yellow sandy mortar joints. At least two different decorative treatments were applied to the inner brick surfaces of the belfry, with a first rendering imitating reddish bricks with pale joints and a second older treatment of varnish with sham motifs.

By digging around the buried part of the foundation, it was possible to measure the different levels, and the tower and differential settlement were found to have sunk more than the church walls. There was a slight difference between the north and south side, but tiered, which is a sign of differential subsidence. On the other hand, the unevenness of the east and west sides was linear, confirming an inclination towards outer esplanade caused by the asymmetry of the widening of the foundations at the beginning of the 20th century.

The constructive discontinuities partly explain the deformation mechanism that affects the southeast corner of the tower's foundation, inserted into the wall of the church, which as undergone serious differential subsidence, with broken and dislocated parts at the bottom. This pathology has been repaired in the past but has occurred again, which is a token of the diachronic development of the phenomena.

Thanks to the correct composition of the foundation system and its good state of conservation, with the exception of the timber stakes, which were seriously degraded (fig. 13), the structural behaviour of the belfry has been monolithic, at least

until the intervention practised in the early nineteenth hundreds: in fact, at that time, no pathology or lesions had been detected in the shaft. On the contrary, although the 1904 consolidation works helped relieve the subsidence process, their lack of symmetry –since they were only performed on one side –probably altered the regularity of the structure and consequently its behaviour, and a lesion appeared on the external prism that can clearly be seen from the transept today (fig. 14).

The results of the preliminary study and even more so the complex structural situation with several breakages in different parts of the walls, deformations and disarticulation of the arches and the ribs in the vaults made it very clear that it was necessary to take urgent steps to consolidate the foundations. In order to choose the best possible intervention, it was deemed essential to prepare a calculation model that would reliably represent the real situation on the basis of the new data discovered. The search for an archive regarding the building phases and the major works carried out for the restoration of the basilica, belfry and adjacent San Pietro chapel permitted the reconstruction of a historic structural analysis and the verification of the kinetic mechanism of the displacements. With this information, a mathematical model was set up taking into account the mutual relationship between the structures and the variations in the distribution of the compressive forces depending on the different configurations that had occurred. The calculation models made it possible to verify the compressive strengths currently present and draw up a hypothesis regarding the increase of values depending on the expected subsidence in the foundations. The study permitted the visualisation of the possible scenarios that could have arisen during the reinforcement of the foundations and some confining interventions were made with the results in case of unexpected problems. A double wooden frame was set up on the disarticulated stone arch to absorb possible further movements of the stone ashlars. The crossing lesion of the belfry shaft was repaired by injecting lime mortar and then adding two definitive braces similar to those inserted in the belfry shaft. And a provisional containing metal brace was

placed at the level of the column between the lateral aisle and the transept to counteract the horizontal thrust created by the natural relieving arch that was generated (fig. 15).

The degree of knowledge acquired by reviewing and continuously comparing the different maps, observations and analyses drawn up during the works and the documents in the archives made it possible to decide on the main aims to pursue in the consolidation project to guarantee the structural solidity and, at the same time, the material and artistic integrity of the monument.

In view of the pathologies of the bell tower, which could hardly have borne any more suffering, it was decided to avoid any sort of intervention that could cause any damage to fabrics that had already undergone serious stress and damage. At the same time, so as not to limit possible future restoration works, interventions like the one performed in 1904, which, apart from producing asymmetry in the foundations, gave rise to objective difficulties for carrying out possible integration works, were discarded.

The analysis of the movements of the belfry and the basilica and the identification of the degradation phenomena showed that the more serious structural problems, such as the lesions and increase of compression found in the fabrics of the church, were the result of differential settlement in the foundations (fig. 16). The trouble was not so much a matter of blocking completely the stability of the belfry as reducing and accommodating the differential settlements of the belfry and the basilica. The application of the usual consolidation methods by broadening the foundations or introducing piles or micropiles underneath involved the need of a system to transfer the loads of the original foundations to the new system. This solution would imply a great deal of invasiveness, material conservation and modification of the tensile states. The modification of the building characteristics and the rigidity caused to the structure of the belfry foundations could also cause problems of incompatibility with the basilica founded on more superficial land and more susceptible to seasonal and environmental changes, due to the peculiarity of the Venetian subsoil, subject to constant

variations of load-bearing capacity and settlement depending on hydraulic equilibrium conditions.

On the basis of the information obtained regarding the composition, geometry and state of conservation of the foundations, thanks to the knowledge of structural behaviour acquired, and applying the principle of maximum material conservation, minimum intervention, maintenance of structural characteristics and minimum alteration in terms of elasticity, the best choice was deemed to attach to the existing structure a new system capable of restoring symmetrical behaviour and reducing settlement, two factors that were considered essential to conserve the equilibrium of the tower. In order not to alter substantially the current equilibrium, it was decided to opt for interventions that could be gauged while the works were being performed and integrated or modified depending on the positive results obtained and verifiable by a system of adequate control.

The technology chosen, and which responded to the pre-established objectives, consisted in consolidating the land around the perimeter by controlled jet or hydrofracture grouting of the area and injection of cement grouting to create a sort of confining wrapping for the pressure bulb. This methodology used in the north of Europe to counteract settlements in foundations had seldom been used in historic buildings and, above all, in high towers with concentrated loads on the ground. The intervention was performed by means of successive selective injections with predetermined contained volumes of cement grouting subdivided in four injection cycles, by almost 2500 valves arranged in 90 fixed sheaths around the foundations.

In each cycle injection took place at the same time from each valve in a vertical direction counterposed to the symmetry axes of the belfry to limit the influence of the intervention on the structure of the tower, whose effects were controlled in real time by a sophisticated system of monitors located in the soil and the principal parts of the tower. The application of the observation method made it possible to evaluate the intervention and reduce it to the indispensable, with a total volume of 100 m<sup>3</sup> of grouting, the equivalent of about

20% of the volume of the soil treated. The penetration probes performed at the end of the intervention showed a considerable increase in the mechanical features of the layers of clay and sand and the tests confirmed that the foundation reticule had been formed (fig. 17).

The intervention carried out on the foundations cannot yet be considered definitive and final. The results during the last year of monitoring reflect a stabilisation of the phenomenon, but only long-term verification will show that the works were a success. The obtainable data of altimetric levels (fig. 18 & 19) indicate that in the year that has gone by since the end of the intervention substantial uniformity of the settlements between the belfry and basilica has been recorded. It is especially interesting to note that the comparison between points 1 (on the pillar at the corner of the basilica) and 5 (located on the western arris of the belfry) corresponding to the impost of the most seriously deformed stone arch:

Period	D (mm)	D/year (mm)
1400-1902	524.50	1.05
intervention to broaden the foundations		
1902-2000	75.50	0.77
2001-2005	4.50	1.12
intervention to confine the foundations		
2006-2007	0.45	0.45

In any case, the phenomenon remains under close observation and, for that purpose, on the basis of the experience acquired, the control system has been optimised, limiting the acquisition of more meaningful data to this phase. Special attention will be paid to identifying the causes of the settlements; if it were found that the degradation of the timber palisade contributes significantly to the structural pathology, it will be necessary to carry out further research into the matter, for at the present time the process of loss of the mechanical characteristics is not clear, and therefore the technology to be used for possible consolidation in the future is not clear either.

The factors that will affect future equilibrium may be numerous and manifold. In the next few dozen years the settlements are not likely to be greater than before the confining works. Then it will be possible to resize and partially remove the braces at ground level installed as a precaution to counteract possible settlements expected during the work

stage and, for safety's sake, estimated to be much greater than in fact they later turned out to be. Should the existence of the settlements not tend to disappear in the years to come or should the tower undergo unexpected inclinations, new repeated injections may be carried out through the same pipes that are already installed, as was done during the works, calibrating and performing the intervention in the sectors and at the depth that are considered necessary and verifying their effects in real time.



**L. Binda, A. Saisi, C. Tiraboschi**  
**EXPERT DIAGNOSTIC**  
**INVESTIGATION**  
**LONG-TERM BEHAVIOUR OF**  
**TOWERS AND FABRIC**  
**STRUCTURES**  
**THE BELL TOWER OF MONZA**  
**CATHEDRAL**

After the collapse of several towers and fabric structures in countries like Italy, the authors have formulated the hypothesis of possible ongoing deterioration of these structures due both to the compression caused by their own weight and cyclic loads (wind, changes of temperature, etc.). The long-term behaviour of historic masonry has also been examined by means of a constant follow-up with laboratory tests and the application of cyclic probes. The results indicate that research both in a laboratory and on site, added to analytic modelling can be fundamental in the case of fairly high bell towers. Below we describe the application of these procedures to the bell tower of Monza cathedral.

The bell tower of Monza cathedral, built in the 17th century and situated 30 km from Milan, with visible signs of structural deterioration, has been studied by the Department of Structural Engineering of Milan Polytechnic in order to defining the state of its lesions. A direct visual examination of the east and west sides of the tower, approximately 74 metres high, showed extended phenomena of cracks dating back at least 70 years. In view of the sudden disastrous collapse of the Civic Tower in Pavia in 1989, causing the death of four people, it was decided to carry out a comprehensive

diagnostic examination including on-site and laboratory probes to analyse the structure in order to evaluate the degree of safety and stability of the tower.

The study of the configuration of the cracks has made it possible to determine a dangerous proliferation of fine cracks between 11 and 30 metres above the ground. Several in situ samples of mortar and brick were taken and later analysed and classified in the laboratory by means of chemical, petrographic, physical and mechanical tests.

In order not to worsen the condition of the masonry, some slightly destructive tests were performed with a flat lack at symptomatic points of the structure so as to accentuate the stress suffered by the bell tower and define the tensodeformational behaviour of the material. The sonic tests have permitted the evaluation of the state of the walls, determining the presence and extent of deterioration.

Finally, the behaviour of the materials was tested according to age and fatigue phenomena. To this end, some samples taken from the wall of the cathedral's crypt of similar age made of similar material to the tower were tested. This extraction was possible thanks to the opening of a passage between the crypt and the extension of the capitular museum.

Then a series of dynamic tests were performed on the tower, using the vibrations caused by the movement of the bells, which made it possible to draw up an efficacious numerical model of the building. The conditions of the tower were also verified by a mathematical model for elastic structures, taking into account not only the effects of its own weight but also incorporating the stress provoked by the wind and changes of temperature. The results of the investigation and the structural analysis permitted the definition and evaluation of the static conditions and the state of conservation of the tower.

*Synthesis of the constructive vicissitudes & description of the first signs of deterioration*

The investigation and study of historic documentation regarding the building stages of the tower (fig. 1) constituted a useful help in the diagnosis of the current state of the structure. The building of the



bell tower dates from the late 16th century. In fact, it was started in 1592, perhaps with Pellegrino Pellegrini's project, and completed in 1605 (Scotti, 1989).

Given this rather short construction period of thirteen years, it can be assumed that there was of project criteria and uniformity in the materials and building methods employed. Unlike the Monza bell tower many other towers, such as the Civic Tower in Pavia, took several years or even centuries to build.

The only really traumatic event for the tower recorded in the historic documents in the archives was a fire that broke out in 1740 (Monza Capitular Archive, Milan State Archive), which destroyed the timber structure of the bells and resulted in material and even the bells falling on the vault of the first floor, 11 metres from the floor. Restoration works were immediately initiated, and continued for several years.

In 1755 the clock was installed and some rehabilitation works were performed.

Other less important events than the fire were a lightning stroke in 1816 (Monza Capitular Library), causing no major repercussion; a tornado in 1842 (Monza Capitular Library), causing slight damage to the roof; and a violent hurricane in 1928, which caused the pinnacle of the cathedral facade to collapse, without damaging the bell tower, however.

In 1927, in view of the cracks in the bell tower walls, two transparent monitoring reglets were placed on the largest lesions in the walls to control their movements. By comparing three photographs taken in 1916-20, 1932 and 1956, it is clear that the most serious cracks were already there in 1832. In any case, there is no record of interventions to stop the increase of this cracking phenomenon and the unsteadiness it was causing (fig. 2). The cracking spread vertically and crosses to the east and west facades of the tower (figs. 3 & 4). The most extended and worrying one is on the main west facade and can even be seen from the square (fig. 6).

Between 1978 and 1998 the cracks were monitored by dismountable extensometers periodically examined, whose data revealed a constant progressive deterioration. In fact, the annual increase of the crack seemed to increase after 1988, which caused serious concern for the safety of the structure.

Figure is a graph of the follow-up of the

largest crack between 1978 and 1998, where we can see a clear tendency to increase, especially fast after 1988. There are other cracks in the internal walls of the tower: they are thin, diffuse, vertical cracks in the four walls of the tower, but especially deep at the height of the passage giving access to the tower, where stresses are concentrated (fig. 7). The cracking is mainly in the bricks and continues 45 cm inside the section of the wall, as demonstrated in a precise examination of the area.

The state of cracking that had developed over the years could be related to the behaviour according to the age of the materials and connected to the presence of a considerable weight (Binda et al., 2003), this phenomenon, together with the effect of cyclic loads like wind and changes of temperature, could cause the structure to collapse.

Similar situations with vertical cracks and sudden collapse were those of the Civic Tower in Pavia, which collapsed in 1989 (Binda et al., 1992) (fig. 9), the Santa Magdalena Tower in Goch, which collapsed in 1992 (Gantert Engineering Studio, 1993) or Noto cathedral, which partially collapsed in 1996 (Iacono B, 1996; Binda et al., 2001 a, b) (figs. 10). Given the situation, it was decided to commission the Department of Structural Engineering of Milan Polytechnic, under the orders of L. Binda and C. Poggi, to design a campaign of tests and experiments to evaluate the state of the tower.

#### *In situ evaluation*

The first information required for a diagnosis is the geometry of the building. Indeed the metric map drawn up was used not only to create a three-dimensional model later transferred to the numerical analyses but as a reference for the successive diagnostic strategies (Binda et al., 2000). In spite of the fact that the largest cracks had been monitored since 1978, no prior documentation of the grounds plans and elevations of the tower was found.

The metric information required included the entity, layout and depth of the cracks in the section of the wall. For this purpose, data of the current state of cracks were taken, documenting the development of the cracks in a ground plan, an elevation

and a section map in order to obtain an overview of the whole so as to make an initial evaluation of the deterioration of the structure as a valid reference for linear and non-linear mathematical models.

#### *Geometric elevations*

In order to save time and money, it was decided to make the elevation of the outer walls by using photogrammetric techniques and the inner walls by using traditional methods. As a support, a topographic network of vertices situated in the cathedral square defined in 1993 was used. Using as a station some vertices of the said network, important points of the west elevation were taken to reconstitute the photographs (Binda et al., 1996, Astori et al., 1992). The photographs were taken with a Rollei 6006 camera, which yielded exact metric references by superposing the image of a reticule of calibration points. The restitution of the images was performed by means of a simplified photogrammetric programme (Elcovision 10). In this way, two products were obtained: a detailed three-dimensional model with which the external and internal elevations and sections were obtained, and a simplified model showing only the essential features of the geometry to be used in the numerical analyses, ignoring details unimportant for calculation. The slope has not been taken into account for the metric elevation because of the slight sinking that affects the square.

#### *Record of the cracks and section of the wall*

The presence of a diffuse crack pattern meant that it was necessary to perform a complete and precise record of the cracks present in the walls of the tower, which were measured *in situ* and in photographs and later reflected in ground plans, elevations and sections. Meanwhile, the development of the larger cracks was controlled, to such an extent that in 1992 it was decided to install an automatic monitoring system. The tendency of three of the monitored cracks to widen was 30.6, 31.3 and 39.7 microns per year in the period from 1978 to 1995, and 41.2, 35.2 and 56.2 microns per year between 1988 and 1997. The cracks in the arris of the north and south facades of the tower, zones that are not accessible from the exterior except by scaffolding, deserve

special attention (fig. 11).

The documentation operations have shown a large concentration of vertical cracks that break the bricks, both on the interior and exterior of the tower from 12 metres to about two thirds of the total height. This situation is perfectly visible in figure 3, where the cracks have been related by superposing the crack maps and the elevations of the tower, in figures 8 and 12 the diffusion of narrow cracks can be seen in the walls that delimit the access to the bell tower. Similar cracks could be seen in the Pavia tower before it collapsed.

The external masonry of the tower is made up of regular rows of brick. In order to find out whether the section of the wall was solid or formed by more than one layer, as is the case in some towers, several bricks were removed and later replaced after taking graphic and photographic data about the interior composition of the wall and the state of cracking inside the probes. Figures 12 and 13 represent the depth of the cracks in the section of the wall and the state of the bricks extracted from the more badly cracked walls, respectively. Four points of the fabric were examined, and the same results and final considerations were obtained. This inspection not only confirmed the fact that the section of the wall is a solid fabric bonded with lime mortar but it also made it possible to extract material to analyse and classify in the laboratory.

#### *Probes*

This research technique is considered to be the least destructive way of obtaining material, and was therefore used at many more spots. However, in the case of materials like bonding mortar, it can pulverise the material during the operation and this be very destructive. Probes only permit the definition of the stratigraphy of the section of the wall, but do not permit posterior reconstruction. In the case of Monza cathedral bell tower, the lack of consistency in the external surface of the bricks did not permit a stable anchorage of the probe rod to the fabric, this compromising the success of the operation. Even so, inspections with a video camera at the orifices left by the probe confirmed the hypothesis of solid section.

#### *Flat jack*

Tests were made with flat jacks (fig. 15) to measure the state of stress and deformability of the material (ASTM, 1991, RILEM, 1990). Seven tests were made on the tower with a plain flat jack, at 5'4, 5'6, 13'0, 14'0, 31'5 and 38'0 metres respectively. The results obtained are shown in figure 18. One can observe how the value of the tensile stress increases from the crown to the base of the tower, with variations due to the presence of openings, more of which are to be found at the bottom of the tower.

The peak stress values are especially dangerous, taking into consideration the characteristic resistance values of this type of fabric that were obtained in the tests with the double jack (Binda et al., 1999 & 2002). Figure 16, for example, shows the results obtained at two different levels. In the same figure the states of stress measured at exactly the same positions with a flat jack can be seen. Table 1 reflects the crack values of the fabric obtained in the tests and shows how the stresses are not very far from reaching an alarming degree, according to the safety factors adopted from codes for new constructions. The results explain the causes of the diffuse crack pattern obtained in the tower.

#### *Sonic tests*

The bell tower of Monza cathedral was also submitted to sonic tests to obtain qualitative data about the state of the walls. If properly calibrated, the sonic speeds can provide qualitative information about large areas of the wall without having to resort to destructive tests (Binda et al., 2000 & 2001). Specifically, two areas at 12 m high on walls of similar thickness, about 1.8 m, were chosen for calibration. In zone 1, the wall can be considered to be in acceptable condition. There are no signs of cracks or lesions, although the previous tests with the flat jack had determined a fairly high stress value in the interior (0.92 N/mm<sup>2</sup>). On the contrary, in zone 2, instability with diffuse cracking was clearly visible. A comparison of the data obtained shows that zone 1 presents systematically higher values than zone 2. the difference can be clearly seen in the frequency histograms in figure 18. later tests confirmed the existence of very badly damaged areas of the wall in the lower part of the tower.

#### *Laboratory tests*

The samples of material extracted from the walls of the tower were classified by means of tests carried out in the laboratory. At the same time some samples were taken from the crypt of the cathedral, which, according to historians, is contemporary with the tower. The tests performed on the materials confirmed this hypothesis: the materials of the crypt and the tower are the same type. As a result, the samples were tested for fatigue and creep to analyse the behaviour in time of a material similar to that of the tower (Lenczner, D., 1982, Binda et al., 1997).

#### *Mortar & bricks*

The samples of mortar and bricks taken from the tower were subjected to chemical, mineralogical, petrographic, physical and mechanical analyses. The aim of the chemical analyses was to discover the composition of the mortars in terms of the kind of conglomerates and aggregates used and obtain information about the degree of alteration. The mortars, which all shared very similar characteristics, comprise aerial limes and siliceous conglomerate, from the Tesino region. Figure 19 shows the results of the chemical tests. It was not possible to perform mechanical tests on the mortar, because it was very powdery. Even so, the adherence between mortar and brick seems good, with the exception of the outer 20 mm of the masonry. The bricks are two different types, recognisable because of the different colour (dark and light red) and distinguishable because of considerable differences in their physical and mechanical properties. The first type is less porous and absorbent (absorption coefficient under total immersion being 13%) and more resistant (compression resistance between 28 and 33 N/mm<sup>2</sup> and elastic module between 2050 and 5300 N/mm<sup>2</sup>). The second is characterised by a greater absorption (18%), less resistance (4÷12 N/mm<sup>2</sup>) and a lesser elastic module (500÷1330 N/mm<sup>2</sup>). Unfortunately there are very few of the dark-coloured bricks. The mineralogical and petrographic analyses confirmed the difference between both types because they were fired at different temperatures. The red bricks, inferior in quality, were fired at a lower temperature (Binda et al., 1996), around

800°C. A larger number of them are present, so they are responsible for the weakness of the masonry.

#### *Creep (viscosity) & fatigue tests*

Earlier publications addressed the long-term behaviour of masonry walls subjected to great compression stress, and demonstrated that they have a viscose behaviour that can cause the structure to collapse after a certain amount of time (Anzani et al., 1995, Binda et al., 1997). It remained to establish whether the masonry of the tower had the same type of behaviour, but there was no possibility of extracting large enough amounts of material to analyse it. Nevertheless, it was possible to extract two large-sized blocks of wall from the crypt of the cathedral when a door into the museum was opened. As we have said, the crypt is believed to have been built at the same time as the tower, and therefore with the same sort of building methods.

Samples of 200 x 200 x 500 mm were taken from the blocks and, after they had been identified, submitted to different sorts of monoaxial compression testing: (i) monotonous, in order to obtain an initial indication of the fabric's resistance values, (ii) cyclic, made at a second stage with applications of cycles of  $\pm 0.15 \text{ N/mm}^2$  t 1 Hz at each load increase and (iii) compression tests by applying successive load stages, maintaining it constant for a period of time defined as about 1.5 hours. As each test took more than a day, the samples were unloaded at night for safety reasons and loaded again the next day.

Figure 21 shows the volumetric deformation stress values obtained during a cyclic test. During the application of the cycles, an increasing deformation process can be observed according as the loads augment. Besides, considering volumetric deformation, dilatation can be seen to take place from the start of the test.

Figure 22 is a diagram of vertical stress and relative time in an essay performed with successive load increases. Viscous deformation can clearly be observed under a constant load. During the application of the last level load, tertiary viscosity appears. Figure 23 shows the cracking pattern obtained at the end of the analysis: a diffuse presence of vertical cracks can be seen, a serious sign of deterioration of the material, to be observed also in the

increase in volumetric deformation and dilatation.

#### *Dynamic essays & numerical modelling*

In 1995 and 2001 two series of dynamic essays were performed with atmospheric excitation to verify the tower's response to dynamic actions and the ensuing effects in terms of stress. Vibrations were induced by the movement of the bells or the wind. The data collection network, set up in the first campaign by six measuring stations and by twenty-one in the second (fig. 24) and the posterior preparation phase made it possible to obtain the modal parameters of the registers in terms of frequency, modal forms and muffling (Gentile et al., 2001 & 2004). Other instruments, such as, for example, transmitted placed over the cracks beside the window at the bottom of the tower, made it possible to verify local situations during the tests. The resulting values, together with the parameters obtained in the other tests performed in situ (flat jacks) and in the laboratory and by taking the data from the crack pattern, permitted us to produce a reliable calibration of the structural model of the tower (fig. 25). The availability of a reliable interpretative numerical model permitted direct control of the structure, providing indications about the stress layout and the possible differences in rigidity all the way up the tower, variations that might be linked to the deterioration of the material and the different building techniques. Furthermore, the tower's response to the action of the wind provokes an important increase in the most serious areas of stress.

#### *Experimental control of the efficacy of the repair methods*

As we have pointed out above, the presence of a great deal of cracks reveals a high degree of horizontal deformation, a clear sign of alarm. The intervention therefore should be directed fundamentally at confining the masonry in general and limiting the dilatation of the material. The reestablishment of a continuity of the masonry by means of local reconstruction works or replacement of the bonding can only be applied locally. In specific cases, because of the great spread of cracks (11 x 9.5 m) and their depth (in some cases over 45 cm out of a total of 140 cm), the recomposition of the bonding or the

exclusive use of braces or chains are not feasible methods to reduce the lateral deformation of the structure.

Among the possible techniques to use for the consolidation and repair of the wall structure, it has recently been studied and proposed to reinforce the mortar pointing especially in cases of deterioration caused by long-term viscose behaviour. This technique can be employed by eliminating a superficial layer of mortar (up to a maximum of approximately 6-8 cm) and placing one or two small diameter rods in the joints. It seems more advisable to use rods made of stainless steel than of FRP. The intervention (fig. 26) can be performed in a straightforward way using fairly ordinary devices, limited to one or both sides of the wall, depending on the accessibility and characteristics of the structure. In both cases, the use of transversal connectors inserted in perforations afterwards sealed can enhance the confinement of the rods (fig. 27), both longitudinally and transversally. These can be especially important for stone walls with interior layers of fillings. The technique is mainly focused on the reduction and containment of the cracks, especially dangerous for the overall safety of the structure when it affects bricks or stones in masonry. The efficacy of the technique and the influence of the different parameters on the mechanical behaviour of the masonry were analysed in two series of experimental tests at Milan Polytechnic in a preliminary phase to intervention on the tower (Binda et al., 2001).

The essays specifically addressed the evaluation of: (a) behaviour under monotonous compression of masonry walls with only one side repaired after prior deterioration caused by compression; and (b) the behaviour of walls with both sides reinforced (but without prior deterioration) under long-term compression, thanks to accelerated creep tests, with modalities similar to those performed on the samples of masonry from the crypt.

The experimental programme for the second series is summarised in Table 2. For this second series of tests, two non-reinforced walls and two reinforced walls were submitted to creep tests. Figure 30 illustrates the geometry and location of the stress.

### *Evaluation of the results*

In the first series of essays, the repaired walls only reached about 50% of their original resistance and presented variable rigidity between 43% for reinforced surfaces and 29% for non reinforced, compared to the original rigidity. In any case, it is important to underscore the fact that the main results were obtained in terms of reducing dilatation and vertical cracks in the masonry. In fact, all the walls showed a reduced crack pattern in the sides that had been repaired, whereas in the sides that had not been, there was an increase in the number and depth of the cracks.

In the second series of tests, the load scheme permitted the reproduction of a very similar crack pattern to the one that could be observed in the real structures. In general, the results of the tests demonstrated an important reduction of horizontal deformations (37-39%, fig. 31) followed by a lesser diffusion of cracks (fig. 29). This point is considered crucial in the classification of the effectiveness of the repair method, preventing the development of the deterioration mechanism identified. All the same, the presence of reinforcement does not have a noticeable effect on the maximum resistance of the wall.

### *Conclusions*

The research carried out after the collapse of the Civic Tower in Pavia made it possible to understand the behaviour of the materials and structures of the old tower. Towers are usually submitted to a considerable weight of their own because of their height and the building methods used. In consequence, the degree of stress at the base can be fairly close to the material's resistance limit, with an increase in viscose deformations under a constant load. In time, this behaviour causes continuous deterioration of the material and can lead to the collapse of the tower.

Similarly, the action of cyclic loads can provoke a sudden increase in local deformations. The combined effect of these factors can reduce the building to a critical state. If its static condition is to be conserved, each possible source of stress variation must be taken into account, including possible concentrations of stress due to geometric discontinuities or the

effect of the wind, the sound of the bells or daily or seasonal changes of temperature. To judge from the results obtained, the tower is believed to have been at great risk just because of its own weight.

As a conclusion to the diagnosis phase and on the basis of the relevant parameters of the specific deterioration mechanism, the efficacy of the intervention proposed was experimentally monitored. The tests indeed demonstrated the possibility of containing transversal deformations, especially hazardous for the overall safety of the structure. The objective is reached by the presence of rods which help reduce the dilatation of the walls and therefore prevents the spreading of the cracks.

### *Acknowledgements*

The research has enjoyed the support of CNR-GNDT, MURST and Monza parish. The authors would like to thank Messrs. P.Perolari, G.Ghilardi, M.Cucchi, M.Antico, C.Arcadi and M. Iscandri for their help and collaboration in the experimental work performed both in situ and in the laboratory.



### **C. Modena & M.R. Valluzzi PROJECT & INTERVENTION ON THE BELL TOWER OF MONZA CATHEDRAL, ITALY**

As is the case with other mass masonry fabrics (ramparts, towers, large pilasters), Monza bell tower shows clear signs of the effect of self-weight, added to some typical pathologies in such structures (serious lesions, collapse, etc.) and recurrent phenomena of physicochemical degradation in the materials that constitute the fabric and its bonding (mortar, bricks and metal braces). In other words, the phenomenon called "*creep*" (viscosity), known to be the cause of some catastrophic collapses both in the past and more recent times (the campanile of San Marco in Venice [Italy], the bell tower of St Magdalen in Goch [Germany], the Torre Civica in Pavia [Italy], Noto cathedral [Italy], etc. – Binda et al., 1991; Binda, Gatti et al., 1992) requires special attention), as it involves extreme conditions due to high states of

compression almost constantly over the years, even though they are a long way from the fabric's maximum resistance capacity (Binda & Anzani 1993, Anzani et al., 2000). The dominant cracks (little vertical or subvertical fissures spread all over the surface) are so unimportant in comparison with other more obvious pathologies that they complicate the recognition of initial or progressive deterioration that could cause the fabric to collapse suddenly (Anzani et al., 1999). The studies carried out by Milan Polytechnic since the early nineteen nineties, based on the extensive experimental and analytical campaigns of some of the most important collapses of recent years (Torre Civica in Pavia, Noto cathedral, etc. – Binda & Anzani 1993) have succeeded in identifying appropriate diagnosis methods to safeguard the existing cases and, in collaboration with Padua University, a specific technique, reinforced repointing, has been developed to counteract the progressive damage suffered by these fabrics during this process (Binda et al., 1999, Valluzzi et al., 2004).

This intervention, not very invasive and easy to put into practice, has been proposed and used in the consolidation of other buildings (Torre Civica in Vicenza, Santa Giustina bell tower in Padua, the pillars of Santa Sofia church in Padua). It consists in inserting small-diameter stainless steel rods (Binda et al., 2001, Modena et al., 2002, Valluzzi et al., 2003a, Valluzzi et al., 2005a). recently the idea of enhancing this technique by using thin sheets of innovative materials like FRP (fibre reinforced polymer) fibres especially in the outside layers of the walls, since they are immune to corrosion, would reduce exfoliation and are less invasive (Tinazzi et al., 2003, Valluzzi et al., 2003b, Valluzzi et al., 2005b). In any case, these studies require further experimentation, especially as regards their behaviour under simulated creep conditions and the problem of anchoring the resistant elements near the corners of the walls (Saisi et al., 2004) before applying them to real-life cases.

A part from the structural fabrics of Monza bell tower, the conservation programme also contemplated working on other parts of the cathedral, for example, the staircase, the roof and the crowning



cornice, in a complete unitary intervention to safeguard the appearance of the building.

#### SYNTHESIS OF THE DEGRADATION CONDITIONS

At a macroscopic level, Monza cathedral presents a major lesion on the western facade giving on to the plaza, increasingly wider towards the top, which crosses the large twin window (fig. 2). This lesion, monitored for over ten years, is characterised by its slow but constant progression (Binda, Poggi et al., 2001). There are also other lesions near the corners of the tower up to a height of 30 m. these can be attributed to the typical pathologies in historic towers, where predominant vertical lesions can almost systematically be observed, accompanied by secondary ramifications, often caused by differential settlement of the foundations. If they are not properly corrected with traces and possibly an intervention of the foundations (Bettio et al., 1995), the lesions described tend to increase in time and can therefore bring about a local increase in compressive stress with the ensuing possibility of crushing, causing local or global collapses due to a lack of equilibrium. Furthermore, the stress analyses performed under the effect of self-weight show that some areas tend to be subject to slight tensile stress, linked to the geometry of the wall thickness and in a horizontal direction (Bettio et al., 1995, Modena, 1994). In these conditions, even a small increase of stress, usually at the level of bays (doors, windows), is enough to cause cracking to begin.

Added to this phenomenon was the typical damage known as creep, with extensive fissures in the bricks and going deep into the walls (even walls of one and a half or two feet) and concentrated especially in an area located between 11 and 25 metres high of the tower (Binda, Poggi et al., 2001). These lesions are mainly independent from those described in the paragraph above, since they can be put down to constant high levels of compressive stresses and, as we all know, can even start at a stage equivalent to 40-50% breakage rate (Binda et al., 1993). The situation may have deteriorated in any case in combination with the first pathologies described, which, by

generating lesions, reduce the continuity of structures and bring about concentrations of stress.

Other interesting elements that strengthen the structure and guarantee the functionality and safety of the building are:

*The inside staircase.* Around the perimeter of the tower are fifteen vaulted stretches of solid brick, each of whose load-bearing structure comprises two rampant brick vaults supported by a stone corbel. This support has two variants: with an element underneath also built of stone or held by a timber brace anchored to the wall by two steel tie beams. The arches have no bond between the bricks and the steps have a rather irregular design because of the way the bricks are laid and erosion caused by use. One section of vaults especially suffers from disarticulation and cracking in the bricks in the central area and loss of geometry because of the rotation of the vaults (fig. 3).

*The roof.* The structure of the dome is made up of a series of curved oak trusses that converge in a king post in the middle by means of several struts and two circular rings of beams laid at the base and the top, where the lantern rests. The surface layer of the roof comprises an entablature supported by the trusses and a sheet of copper on top. The curved lower beam (sleeper) presents deformation and pathology as a result of a concentrated lesion, whereas the timber tie beams near the king post are especially badly degraded due to a parasite attack (fig. 4).

*The upper cornice.* The cornice of the tower is located at about 70 m above the plaza and comprises three rows of Serizzo granite ashlar, moulded and overlapping, with a maximum projection of 90 cm. Gaps and serious cracks can be seen in the ashlar, particularly at the corners of the cornice (where there are ornamental elements that gravitate directly around them), as well as chromatic alterations due to the effects of oxide around the preexisting clamps and fittings (fig. 5).

#### STAGES OF THE PROJECT AND INTERVENTION

The project for the intervention to be carried out on Monza bell tower went from a preliminary stage, consisting in defining the steps to be taken in order to restore structural safety immediately

(injections and sealing of the cracks in the areas of more serious damage and/or deterioration, confining and the insertion of metal clamps at different heights of the shaft of the tower, and reinforced bonding of the layers of mortar to soften or stop deterioration caused by excessive compression), to the final stage, where the materials, methods and techniques to be used were identified, following conservative criteria (compatibility, minimum intervention, reversibility and minimal invasiveness), the latter thanks to the fact that quite detailed preliminary studies were available (Binda et al., 2003; Modena, 1997). Massive reconstructions of the damaged fabric were avoided as much as possible by applying localised reinforcement consisting in inserting small amounts of small sized frames inside the mortar joints and preparing the most suitable mixtures for injections and repointing (to use in sealing cracks and filling in gaps in the mortar, respectively). The impact of the intervention with the reinforced repointing contemplated in the project was finally quite scant, limited to some strips of the inside walls, much weaker and in a poorer state of repair than the outside (Binda, Poggi et al., 2001), and some parts of the seriously damaged external pilasters without intervening on the very well conserved external surfaces (with the exception of cases of localised degradation caused by phenomena of a physico-chemical nature), for which the usual measures were used: replacement of some bricks and localised repair of degraded mortar joints. Finally it was decided to perform work on the internal structures and accessories (staircase, cornice), and on the roof.

A very peculiar aspect of the conservation works, not directly related to issues of structural security, is the treatment of the surfaces. Lacking specific indications, this matter was addressed in the preliminary studies. The project initially contemplated a general cleaning process (with some techniques to be decided during the works on the basis of concrete tests –microprojection, cleaning with vegetable bristle brushes, poultices, water spray) and, immediately followed by procedures for consolidation (with ethyl silicate) and protection. On the basis of the data found and the specific studies performed on the surface crust of the mortar joints, this

choice was changed completely. In fact the crusts were found to pose no danger whatsoever for the conservation of the materials in the least and, on the contrary, they might even protect them.

Furthermore, the analyses detected that the surface of the mortar joints contained a large proportion of gypsum, which has formed a very stable protective coat. In this context, cleaning would mean worsening the protection conditions of both bricks and mortars by eliminating the existing protective layer, perfectly valid and useful, and replacing it by treatments with doubtful outcome and limited duration. Therefore it was decided not to go ahead with any of the surface interventions (cleaning and protection) initially contemplated in the project. Below is a description of the fundamental aspects of the major intervention techniques designed for the tower and which were under way at the moment when this article was written.

#### *a) Metal clamps*

Several solutions of metal clamps were proposed depending on the different building conditions and accessibility identified at different heights of the building. These clamps generally comprise brackets internal braces; the former are made of corrosion-proof steel and the latter of stainless steel. The threaded metal rods of the braces have a tensor to adjust from the inside of the structure. These devices endow the constructed fabric with a confining effect, apart from enhancing the reciprocal bond between the walls in general. Figure 6 shows the general scheme of the different proposals, while figure 7 shows some details of the solutions put into practice. We can see six clamps, one in the foundations and the rest along the shaft of the tower up to about 42 metres. The latter can be classed in three typologies, indicated with the letters A, B and C. The former two of these are inserted in the interior of the structure whereas the latter is entirely external. Type A clamps comprise a couple of rods of 39 mm diameter, inserted into holes bored into the walls and anchored to external stainless steel plaques. Two different solutions were used to anchor the braces, according to the accessibility of the different areas: the first involves the transversal union through the corner by

means of a triangle of tense cables (for the clamps located at 5 and 11 metres high), and the second a series of rods inserted into the joints and spread along the areas occupied by the external plaques. The presence of a vault of some 11 metres high gave us the idea of constructing in the extrados an authentic confining diaphragm (type B clamp). Consisting of a rectangular frame of U bars reinforced with angle braces at the corners and braces tightened by tensors. The system was assembled in situ with nuts and threaded rods, adjacent to the inside walls, attached to them by repointing with expansive mortar and inserted under the pavement over the vault present at the same level. The only completely external clamp was located at the same level as the cornice, 42 metres over the plaza, and comprises pairs of braces 36 cm diameter attached to plaques at the corners. This structure was built entirely of stainless steel because access was difficult should maintenance be necessary.

The results of the in situ monitoring and structure inspection could confirm the need to insert a retaining ring at foundation level. This would be made of a reinforced concrete clamp attached to the structure and fixed by sets of three post-tensioning Dywidag type threadbars inserted into perforated holes.

#### *(b) Intervention on the surfaces*

Several intervention techniques were used to rehabilitate and reinforce the fabrics. To counteract the evolution of damage caused by creep, reinforced regrouting with small-diameter bars inserted in the layers of mortar was considered, which has a confining effect on the fabric (in practice the effect achieved is similar to inserting fibres into the mortar and concrete, which, although it hardly affects the resistance features, it increases the fracture energy considerably). For local rehabilitation of the walls in especially badly damaged areas, support techniques like injections, coursed repair of cracks, and repointing of the gaps in the joints were planned. The number of bars and the space between them depends on the degree of degradation; in the case we are dealing with, the decision was to insert pairs of 6-mm diameter stainless steel bars with improved adherence in every two layers of mortar. This technique was used in general

in the areas with many cracks caused by the phenomenon described, but also locally, to reinforce the external corners and in places with localised crack clusters (see fig. 7.c). As we pointed out above, the technique for repairing cracks, both in very badly damaged areas and in isolated cases, was only applied to the inner walls of the tower, where the lesions were especially severe. The action of the reinforced bars was augmented by inserting transversal connectors (comprising metal rods bent to form a U shape) arranged inside sloping perforations later repointed with mortar, which also contribute to reinforcing the connection of the walls with the central nucleus.

The intervention for the reinforced repointing was distributed over the four sides in sections between 11 and 28 metres high and at the crown of the tower (between 40 and 45 metres high). The corners were reinforced with the same technique on most of the central area of the tower (between 11 and 37 metres high), above all on the northern and eastern facades. The repointing of the gaps in the joints was found to be especially necessary at all the crown of the tower, both in the exterior and the interior (from 37 metres high approximately). Finally, the sealing of the cracks was limited to some sectors located at the top of the tower (between 40 and 45 metres high, interior only) and the bottom (up to 20 metres high, both interior and exterior), where some injections were also required in places.

#### *c) Intervention on the internal staircase, the roof and the crown cornice*

The safety tests carried out on the vaults of the internal staircase showed that they were mostly free from tension and the timber and metal supporting the intermediate corbels with guys and braces were not in critical condition (fig. 9). On the other hand, it was necessary to act on the stone corbels due to very serious tensile stress, so it was decided to use steel clamps to bear this flexion stress and leave the existing corbels only the task of resisting compressive stress. Particularly, in the case of corbels with sub-corbel elements also made of stone, a flat stainless steel bracket was placed around the corbel, anchored to the wall by

stainless steel rods with improved adhesive bonded with resin and welded to the metal bracket. The intervention was estimated to keep the tractive forces low enough in the stone if the barycentre of the steel plate is placed no less than 10 cm below the lower edge of the section (fig. 9).

No resistance problem was detected in the stone corbels with timber braces anchored to the fabric by means of two steel guys. In any case, the state of repair of the braces and the security of the steel anchor guys should be checked during the works. The intention is to replace the heads of the braces if they are rotten with solid or laminated wood prostheses, inlaid and assembled with screws to guarantee the duration and structural functionality of the brace (fig. 10b). The same material and philosophy can be used for the new timber elements as for the existing ones, taking care not to bond elements with a different degree of humidity from the existing wood. The reliability of the existing steel guys can be guaranteed by inserting a stainless steel rod with improved adherence, bent so as to form two parallel arms, bonded with resin at least 40 cm inside the wall. The mortar joint cleared away for its insertion will be repointed with lime mortar.

Finally, in the case of the two connected vaults where the corbel is missing, the plan is to insert a new corbel to absorb the load stress of the vaults completely. This new corbel will be made of high quality wood so as to distinguish the new elements from the old stone ones and, insofar as geometry is concerned, the typology of timber corbel with a brace is recommended (fig. 10a).

The analysis of the finite elements at the top of the little dome on the roof, made by several in situ inspections, informed us of the compressive strength of the resistant elements, not excessive considering their resistance and deformability (fig. 11). In any case some interventions are planned to improve the structure and the connections between the different elements.

In the intersections of the pieces that form the roof trusses, metal bands will be screwed on to hold the finite elements more solidly together. The model of finite elements also provided information to measure two annulets to be made with the help of cables and located at the

intersection between the rafters and struts (annulet A) to increase the stability of the braces against wind of the trusses and as a connection of the 16 trusses that form the curb of the dome (annulet B), in order to absorb part of the tensile stress that acts on the sleeper and prevent the dome from possibly cracking due to the effect of the wind (fig. 12). Furthermore, the overall stability of the elements of the eight rafters exposed to the wind is guaranteed thanks to the insertion of two new first-class timber elements connected by draw bolts to the bands and arranged in such a way that they act as props or braces, depending on the direction of the band course of the rafters.

As regards the damaged sleeper that appears in figure 4, the solution is to screw on round filleted stainless steel metal bands bonded with resin. In any case, an insecticide and a fungicide will be applied to all the timber elements in the tower and the state of the fabric will be checked at the points where the trusses rest, and, if necessary, the cracks will be repaired and injections and repointing will be carried out.

The repairs of the stone cornice at the crown, 70 metres high, will consist in general consolidation works on all the stone elements with the help of butt hinges, strips of carbon fibre and microinjections in all the cracks, and the construction of a flat curb that will guarantee that the stone elements will not come loose from the cornice by means of an anchorage system.

Particularly, the reinforcement solution comprises three sets of elements: clamps on the upper tambour, four corner curbs and a series of anchor braces (fig. 1 & 13). The clamping of the upper tambour, carried out with calendered profiles, fulfils the double function of rigidising and forming the anchorage base for the corner curb and the tie beams. The corner curbs are made up of square section tubes arranged in such a way that they can cover all the stone elements around the stone ornamental columns located at the corners. The structure consists of stretches of tubular profile pre-welded in the workshop and assembled in situ with threaded rods and bolts. The anchorage braces comprise plaques connected to the stone elements by means of rods and resin. A certain amount of deformability was expected at

the joints of the curbs and the clamps to avoid damage caused by thermal action. If the reinforcement structure of the cornice were exposed to the exterior of the tower the damage could be quite serious. In fact, possible dilatation or retraction of the anchorage braces after the installation could cause coactions that would not be tolerated by the stone elements. To avoid this problem, the idea was to put springs in the connection between the anchorage system of the braces with the curb structure (comprising the clamps and the horizontal corner curbs), to permit dilatation of the brace from thermal action, maintaining the tensile stress within the required limits. To complete the anchorage system a strip of carbon fibre will be placed on the upper perimeter and consolidating microinjections and metal clamps will be inserted in some of the damaged or loose parts of the stone cornice (fig. 14).

## CONCLUSIONS

Apart from monitoring the most serious lesions (which has gone on without interruption since 1978), the preliminary survey carried out by Milan Polytechnic made it possible to detect the most seriously damaged parts of the tower and the causes of these pathologies. The situation of the structure required immediate intervention without further control. The intervention project therefore focused on the consolidation of the tower. The close collaboration between the project designer, the researchers from Milan Polytechnic and Padua University and the constant contact with the Soprintendenza made it possible, in the first place, to reduce the structural intervention to the absolute minimum and, in the second place, to avoid washing and applying detrimental treatments to the external surfaces because of the presence of joints with gypsum. This collaboration, the inspection and suggestions of the National Council of Cultural Assets of Italy –performed by the Committee of the Environmental and Architectonic Aspects Sector and the Soprintendenza–contributed to put into practice a project with functional variations drawn up with the greatest possible respect for the existing building.

