INTEGRATED METHODOLOGIES OF REPRESENTATION AND ANALYSIS OF A GREAT MONUMENTAL STRUCTURE: SAN LORENZO MAGGIORE IN MILAN

C. Achille, S. Bozic*, R. Brumana, L. Fregonese, C. Monti, G. Monti*, C. Savi, R. Virgilio*

DIIAR, Civil and Environmental faculty, Politecnico di Milano, piazza L. Da Vinci, 32 – 20133 Milan

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ABSTRACT: San Lorenzo Maggiore in Milan: advanced survey.
San Lorenzo is a paleochristian Basilica which consists of a central tetraconical body with connected chapels. It is subject to a series of stratigraphic, material and historical analysis to establish the dating of every part of it. The entire work is based on a complete surveying system with the aid of the most update instruments.
This implies the planning of maps, sections, and orthophotos with the use of digital cameras, laser scanners and no-prism theodolites together with the implementation of data in a GIS.

1. MANUSCRIPT

1.1 Introduction

The Basilica of San Lorenzo Maggiore can be considered an extract of history and a chronological story of constructive techniques of Milan because it represents a sort of stratified "deposit" of 1600 years of yard activity, from its foundation occurred in late-ancient ages to the Medieval and late-Renaissance reconstructions, until the interventions of restoration in the XIX and XX century.
In the Laurentian complex, from the end of the IV century, up to the middle of the XIX century, interventions of construction, modification, maintenance, reconstruction and also important enlargements for the use, have stratified.
The architectonic literature considers it one of the most extraordinary structures of the western Mediterranean area because it is a very articulate aggregate of buildings, without a stylistic unity and still of difficult interpretation and comprehension.
With the restoration yard there was the occasion to lead a work of metric and archaeological knowledge, with the aim to finally verify the foundation date of the different parts of the building, the paternity of the commission, causes and entity of the breakdowns occurred in Medieval and Modern ages, the systems of plans and elevation layouts linked to the dynamics of the old yards.
The problem of the original destination has recently been tackled with the help of the absolute dating led with radiocarbon 14 and thermoluminescence.
Researches have allowed to set the original nucleus of the structure to the years following the death of Sant'Ambrogio and the emperor Teodosio, in the period dominated by the general Stilicone, temporary regent of the Roman Empire.
The new archaeometrical dating together with data already known in the past has permitted to reject previous hypothesis and in particular the ones of Aryan church, Palatine chapel or Basilica Porziana.
The Laurentian complex constitutes the part of a magnificent project of memorial dynastic architecture, a *heroon* mausoleum designated to the new family of Teodosii, expression of the new politic power of the city of Milan, capital of the Roman Empire.
The private financial support has permitted the use of leading methodologies in the survey and archaeometrical fields (absolute dating and material characterization).
The complexity and the quantity of data collected will lead to the editing of an informative system that will include data and their correlation in function of more parameters.

1.2 Survey and knowledge

Discussing about survey implies the knowing quantitatively the Architecture, claims understanding the meaning of knowing.
We can speak of knowledge in general, but we can also concentrate on what a cognitive progress expresses in research, conceived as the approach to a pre-established purpose, for example the knowledge of the architecture through its measurement (survey), its representation (views, vertical and horizontal sections), its analysis (the archaeometrical ,materials..).
What we ideally pretend from science through knowledge is a precise representation-description of the fundamental aspects of reality, deeply connected between themselves. Knowledge passes through different stages of analysis, waiting for a synthesis that only rarely comes true. San Lorenzo is a typical example of different doctrines converging to achieve an analysis that leads to an explicative synthesis of the different aspects of the Basilica.
Nevertheless the goal of the knowledge of the Basilica in its material, historic, geometric… aspects reaches a high level, that further knowledge developments could even elevate, giving for uncertain what was given for sure.
The survey progress is underlined by the reduction of the uncertainty of measurements.
Even during Galileo's times these measurements had much bigger uncertainties than today, but the measured quantities were also less.
In San Lorenzo it is clear how the increasing number of measures and the reduction of uncertainties about the coordinates of points, due to the use of new

* Sandra Bozic, *email*: sandrabozic@hotmail.com
* Giada Monti, *email*: giada.monti@polimi.it
* Roberta Virgilio, *email*: pebs@softhome.net

instruments, show "geometric anomalies" that don't have a logic explanation but simply depend from the uncertainty of past tracings.
Survey in this case reproduces of the state of fact, pure knowledge through representation.
Today science and technic are not separated and autonomous anymore, but they are more and more interconnected.
Measure is the support of this exchange.
The quantitative knowledge of the architecture, consisting in its measurement through the survey and subsequently through its representation, leads to the model that can be considered a sort of image of the state of fact to which in these centuries, different projects and stratified realizations concurred in a chaotic order.

1.3 Survey and representation
The different spatial dimension of survey requires different methodologies, precise solutions, and adequate instruments.
Unlike territorial representation, that cartography well supports and where planimetry is in general privileged, in architecture each of three spatial dimensions (X,Y,Z) have an equivalent importance. In general, unlike territory, the architectures have an inside and an outside and the survey for the inside often requires different techniques and instruments from those necessary for the outside.
San Lorenzo makes this distinction ephemeral because the outside seems an inside (niches, undercuts, recesses..) and the inside space is composed by solids, vacuums, volumes at different heights that render the survey difficult independently from the used instrument. Therefore an external and internal grid reference system on different levels of the monument that allows to supply references to its constituting parts in a unique system is necessary. Thicknesses, distances, volumes, trends, surfaces are in this way rebuildable starting from the simple differences of spatial coordinates.
Survey methods can't leave out of consideration (San Lorenzo is the validation in the field) the "banal" methods of direct measure, despite of the sophistication of the current technology.
The object is shattered in a set of punctual characteristic points such that their possession leads us to the knowledge of the masterpiece in its wholeness.
The transfer of typical methods of the cartographic survey to architecture, hoping of obtaining for analogy the same results achieved in cartography, is not a practicable path without correctives and principles of validation. In fact surveying architectures, the correlation between the purpose of the survey and the elements to survey, not only is much more selective and discriminant but also more subjective. It is true that some type of homologation, at least in the most diffused scale, 1:50, has been used (vide the first specifications), but, as usual, foreseeing all the following necessities is very difficult especially when problems come out one after the other, caused one by the other.
The discretization in points of survey highlights the entire problematic limitation of the method, and the curious thing is that, while not long ago the problem seemed to find its limit in the scarcity of points necessary to represent the structure of an architecture, today it's the opposite with the scanning-laser.
Obviously the photogrammetrical method survives and it is not disjoined, at least in part, from the applications of the new methods admitted by the instruments and the computer science.

1.4 Forms of bi-dimensional and three-dimensional representation
There is a consolidated tradition on how to represent graphically on a plan the three-dimensional objects, but there isn't a consolidated tradition on how to represent them graphically on a three-dimensionally plan. But it is immediately necessary to specify that when you enter in the three-dimensional field, the photogrammetry is a sharer technique, with the others, to achieve the final result. It's clear that here for 3D we mean those shapes that can have an effective and three-dimensional representation (i.e. in the bi-dimensional representation on video or on paper, the points that I see are affected by three coordinates and therefore their position is known in the assumed reference system), observable from different points of view once the model of reality is carried out.
Whether the model is obtained through the photogrammetrical method in some cases, or through new methodologies based on the acquisition in short times of clouds of points of the object in an opportune system of reference, the problem of the representation of the object always remains.
Basically one of the most important advantages of using the photogrammetrical system is that it has already been tested many times, therefore it produces extraordinary results where it is practicable and convenient, whether generating vector representations, or raster ones (photoplans) when possible, or the ones usually called 3D orthophotos. These last ones which need the construction of the DSM (Digital Surface Model), which can be partially computerized, work out the model dressed with the orthorectified digital images of the surfaces.
The laser scanner system creates the image of the model using millions of points, the so called *cloud*, but it is a representation that can't be used by itself. It must be depurated from the abnormal points using sophisticated algorithms because of their high numerosity. These algorithms have not yet been adequately tested on big numbers and are run through software packages created for other purposes and only recently present versions that help solving this problem. Once you obtain the *"clean cloud"* of points, difficult to achieve in complex cases like San Lorenzo, you can start the research of three-dimensional representation.

1.5 Survey Grid Reference
Photogrammetry, in its classical feature or in the new digital othoprojective one, needs the aid of the essential topographic operations on the territory. These are made up of a highly precise reference grid that embraces entirely the monumental architecture; it builds up the frame within which all the survey develops, and its purpose is to stop the propagation of mistakes proceeding from general to particular views and it is characterized by permanent reference vertexes.

Secondary grids descend from main ones with the purpose of taking coordinates to the interior of the rooms where you can place *Total Station no-prism* instruments for tacheometric surveys in order to define coordinates of spots on the object, to find its position in the reference system in which the main grid has been built and to fix visible points on the frames, the so called anchor points, in order to orient these to the outside. Recently a new logical necessity has been pointed out. Every survey must be framed in a single reference system and it should have the possibility of referring itself to the cartographic national reference system (georeferenciation). Georeferenciation is an essential step when surveys are part of or are framed in a Geographic Information System (GIS). From the analytic or digital orientation of the frames we pass to the generation of the DSM of the surface. In complex cases, especially with a very high number of frames, the automatic definition of many points in order to correlate different images can be achieved through *aerial triangulation* in order to build the DSM on which the raster 3D digital orthophotos can be spread.
In San Lorenzo it has not been possible to limit the survey and representation methods to one single technique. It is the typical situation where the most modern techniques (laser scanner, digital photogrammetry,…) must be mixed up with the ancient ones (manual-direct survey). Only through the integration of these operative procedures, a complete and exhaustive representation of the monument can be obtained.

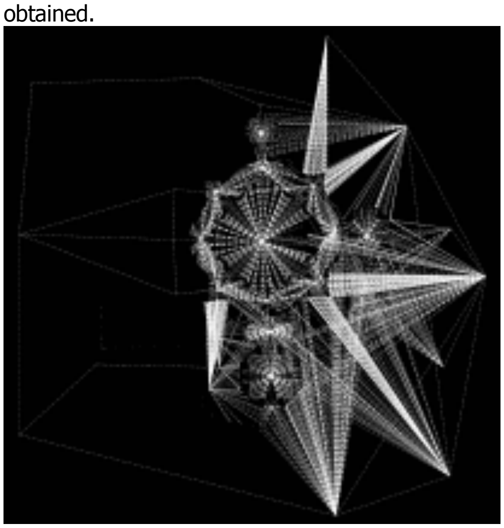

Figura 1

1.6 Used instruments, software, mistakes, direct integration.

San Lorenzo survey has been brought out using three mechanized theodolites of the last Leica production (TCRM 1103, TCRA 1103, TCA 2003), whose precision characteristics are well known (several ten thousandths of grade for the angular directions and some millimetres for the distances). Two of them were supplied with no-prism laser diastimeter for tacheometric survey of interiors, exteriors, and anchor points. The third, the most sensitive on the market, was used to establish the grid reference. The whole external part and in the intrados of the cupola in the interior have also been set out with the LMS-Z210 Riegl laser scanner. In the inside the Callidus laser scanner has also been used.The software used to process the clouds of points are the following: 3D Riscan, 3D Extractor (Software owners laser scanner), Spider, StudioTools (Alias Wavefront). The uncertainties in specifying tacheometric points are always compatible with the representation in scale 1:50 (0,2mm graphic error), that is the centimetre. Even the exteriors and the interiors determined with the laser scanner are consistent with this accuracy. The integration with measures taken directly with wooden ruler, measuring tape, disto, always georefernciated to the tacheometric points in the editing stage, has been outstanding.
The photogrammetrical frames in the interior and in the exterior of the Basilica have been made with the new Rollei *db44 Metric* digital photogrammetrical camera with 16 millions of pixels on a frame of about 40mmx40mm (1 pixel=9 micron) for the reproduction of parts of the Basilica with digital photoplans, where possible, and digital orthophotos.

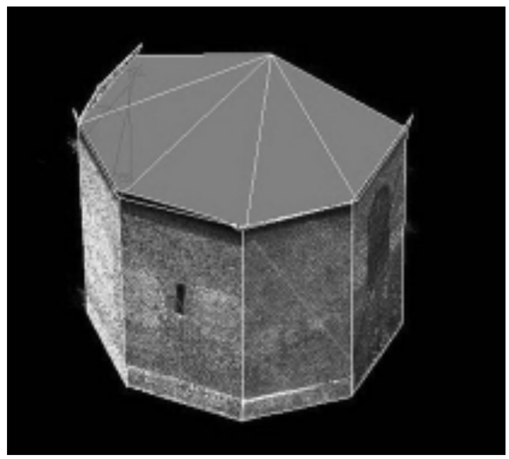

Figura 2

1.7 Plans and sections

To this day the horizontal section at 1,50m of height from the step floor has been completed at the nominal scale of 1:50. The plan has needed the use of the above said instruments, in addition to the definition of "eidotipi" (sketches for drawing plans) with the direct integration through the use of measuring tapes, wooden rulers and distos: everything processed with Autocad Map 2000.
The part of the section that has been surveyed by now has followed the same procedure excluding a larger use of the laser scanner system, no-prism theodolites and a reduction of the direct survey because of the inaccessibility of many places. The survey of the basement will also follow the same method.
Some digital photoplans and several orthophotos have been made for the exterior part (fig. 2) starting from images acquired with the Rollei db 44 metric. The photoplans, have been oriented and analytically scaled on at least six anchor points. The resolution of these frames is precise enough to support the scale 1:50, but also 1:20 without loosing definition. Surveying can be considered the natural support to the georeferenciation of all the different kinds of analysis started (mensiochronology, chemical analysis, thermoluminescence).

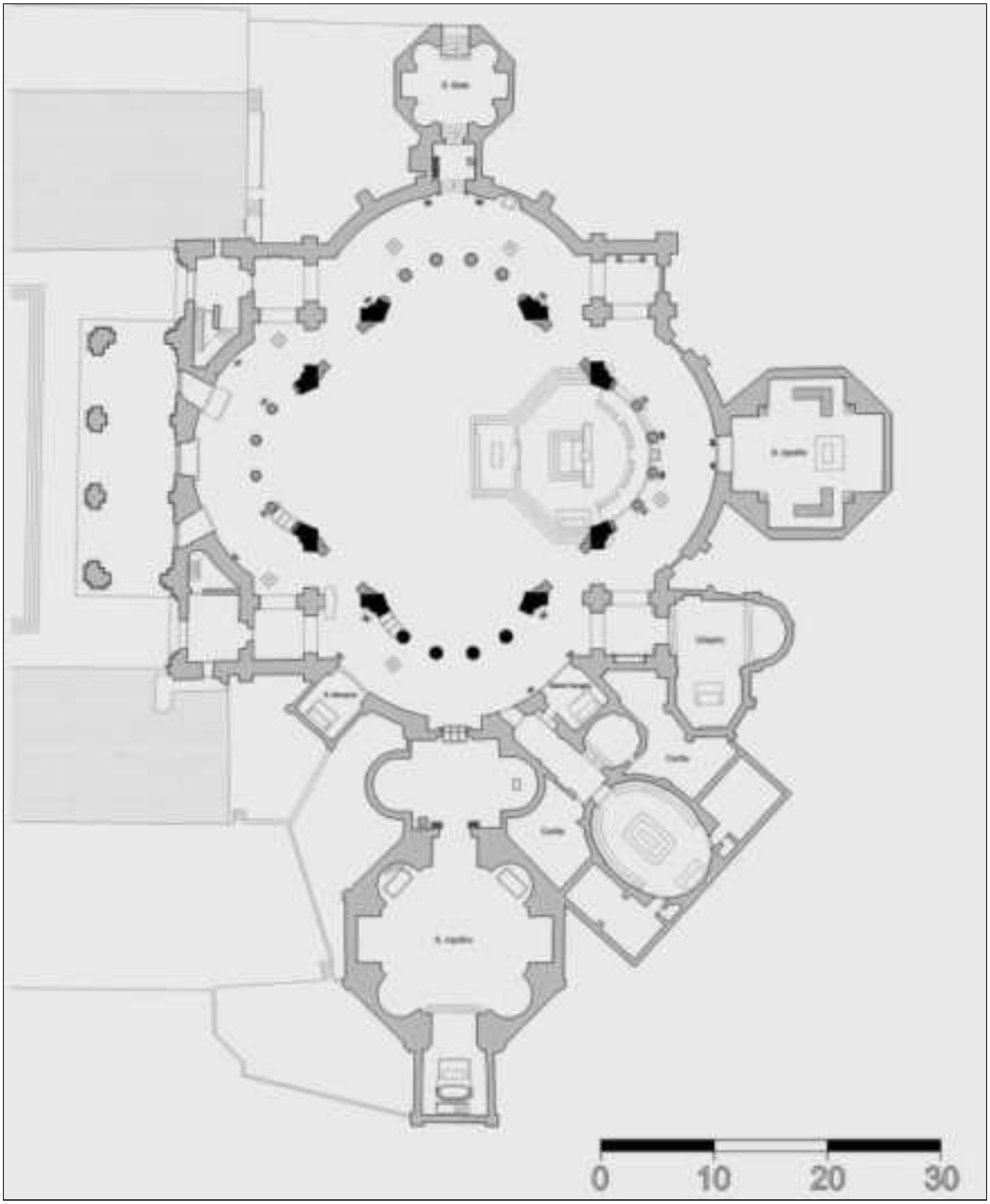

Figura 3

1.8 Geometrical analysis of the plan: first elaborations

A first elaboration has been made in order to study the geometry and the hypothetical criteria of the scheme and layout of the plan.

For example, in the tetraconco the four circumferences generated by the four sectors of the exedra have been defined through the minimization of the square deviation between the surveyed points (about thirty) and the circumference interpolated through the same points (fig. 4).

The hypothesis that the exedras belong to a circumference appears to be logical a posteriori either for the radial deviations obtained between the real position of the observed points and the interpolated circumference, or for the root-mean-square deviation of the four calculated radiuses, or for the fact that the four radiuses are similar. The four interpolated circumferences which are obtained from the points belonging to the curvilinear parts of the eight bearing piles, considered two at a time corresponding to the relative exedras, set out circumferences nearly concentric with the ones said above and with the diameter similar to their radius, considering the relative root-mean-square deviation.

Figura 4

It can be highlighted that the circumference interpolated on the four piles relative to Sant'Aquilino is tangent to the four octagonal columns while the other three groups of four columns each have a distance from the interpolated circumferences of a maximum of 35 cm in the centreline.

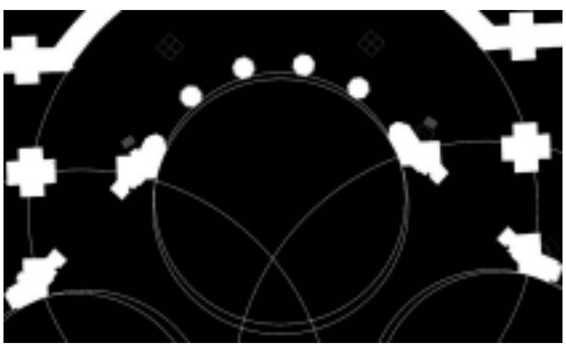

Figura 5

Building the circumferences that interpolate the groups of columns of each sector of the tetraconco, you find out that it adheres perfectly to the columns but it crosses the curvilinear parts of the piles (fig. 5).
The translation of three of the four circumferences doesn't change the geometry and the dimensions but it must be expanded with new hypothesis and elaborations considering the up-to-date results. Gathering the pile points and the curvilinear sector points worsens the outcome and the adjustment of the circumferences to reality.
It is clear from these first deductions that the four interpolated circumferences of the exedras of the tetraconco are inscribed in another circumference perfectly tangent to the extrados of the sectors of the exedras. Even if this hypothesis could explain the layout operations and the project genesis, we must be careful and deepen our studies before drawing conclusions that have only a probability of being true.

1.9 Archaeological and archaeometrical studies

The archaeological and archaeometrical research has studied all the structures in a vertical sequence, from foundations to coverings. Thanks to the characterization of the various stonework techniques and to the stratigraphic analysis (fig. 6,7 e 8) of the walls of each part, many different construction stages have been isolated, grouped in periods and tested with radiocarbonio14 and thermoluminescence. Some original parts of the floor have also been put through the stratigraphic analysis, just like piles and supporting columns, as well as decorated surfaces (mosaics, frescos, plaster).
All the building techniques of the walls, in stone or in brick, have been characterized and deepened with the description of texture, mensiochronologic and chemical-physical characteristics of the mortars. The single techniques have also been dated one by one. A cataloguing operation of all the details surveyed has been set.
All the building stages have been historically defined in order to insert them in the three-dimensional model resulting from the survey, which will represent the structural evolution of the building and that will allow the reconsideration of what has been deducted from documentary sources, in the light of the last archaeological results.

2. SURVEY COMPLETION AND ANALYSIS

The plan at the women's gallery level, two principal sections and the model of one of the most complex sectors of the tetraconco has been arranged.
All the data resulting from the survey, from the archaeometrical and material analysis, rendered numerically congruent in the space, will be gradually systematized in order to be processed in a GIS.

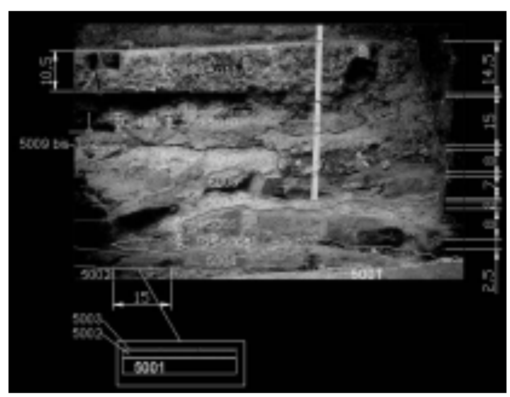

Figura 6

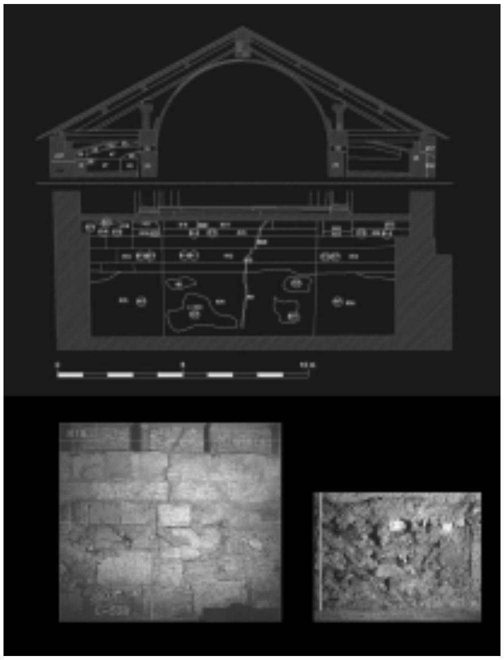

Figura 7

The synergy between heterogeneous techniques and different abilities has brought to an excellent knowledge, wider than the one achieved through the previous extensive archaeological and architectonic literature. We hope that in the future this new kind of knowledge will be able to achieve, thanks to the different means public information, the repossession of this architecture also from a profane public.
As Peter Brown, one of the most important historians of the late ancient period, said you can't give or realize any kind of historical knowledge, even on a basis of a large number of data, without the support of the imagination or better of the construction of *imaginative models*, which are the mixture of fortuitous data and the past lost shape.

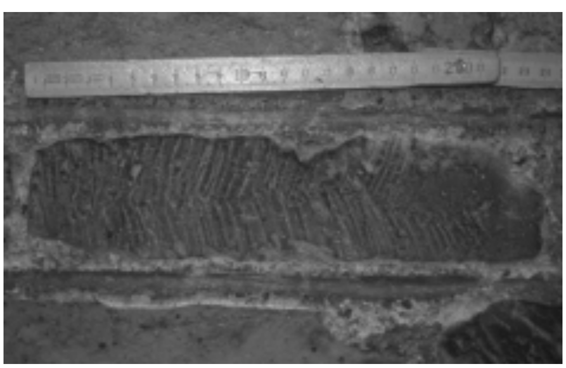

Figura 8

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