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The church of St. Saturnino in Cagliari, Sardinia

Reading the levels of history through the use of digital survey and the petrophysical study of materials

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Abstract: The most ancient church in Cagliari is dedicated to Saint Saturno (commonly named Saint Saturnino), the first indications about this church come from the sixth century, but the building arrived to our time is only a part of the original one and it rises over the ruins of previous structures, inside a walled area with the presence of a Palaeo-Christian necropolis. The original Greek cross plan, with a transept and a semi-spherical dome, has seen meaningful transformations in time, with the partial destruction of large parts of the building. All the four arms had a nave and two aisles, but the current church consists only of the dome-covered part and of the eastern arm, with a nave and two aisles. The whole church shows very interesting spoils coming from previous architectures of the Roman age, a rich catalogue of materials and details. In summer 2013, a collaboration between the Departments of Chemical and Geological Sciences from Cagliari and the one of Architecture from Florence brought to the realization of a detailed study about this ancient church. The whole building and its surrounding area were surveyed with the following methods: photography, 3D Laser Scanner for the whole interior and exterior parts, photogrammetry of a selected set of stone surface samples, direct sampling of significant rocks and their geochemical and petrophysical analysis. All data were then treated and analysed to deepen the knowledge about the most meaningful aspects of different construction techniques and use of materials, provenance of raw materials, stone and structure alterations. As result, a base was created to read common features, design choices, recursive constructive solutions, and the "models" guiding the ancient intentions. This contribution will present the progress state of this research and its results.

Keywords: 3D Laser Scanner, Sardinia, petrophysical study, San Saturnino, Romanesque.

Introduction

The research presented here is a part of a wide project called: "The Romanesque and the territory. Construction materials of the "Sardegna Giudicale": new approaches for the valorization, protection and restoration" [COLUMBU S., VERDIANI G. (2014c)]. Starting from the 2012, this project has seen the collaboration of a team from the University of Cagliari, the C.N.R. in Cagliari and the University of Florence. It has been financed by the regional government of Sardinia (*Regione Autonoma della Sardegna*). The main task of the project is to allow a correct reading and documentation of the system of Romanesque churches in Sardinia. In details the structure of the project is articulated around four main tasks: 1) the comprehension of this Architecture language in its particular sardinian declination; 2) the comprehension of the single building;

3) the comprehension of the arts applied and related to each monument; 4) the comprehension of the materials used in these churches. To allow a complete and detailed development of these tasks, the team working on this research project is composed by: *Dipartimento di Scienze Chimiche e Geologiche* (coordination, sampling of the materials, physical and petrographic analysis), Cagliari University; *Dipartimento di Architettura*, Florence University (digital survey, 3D laser scanner, photogrammetry and data treatment); C.N.R.- IGAG (National Research Center), Cagliari Unit (MSA analysis, XRD analysis of the material surface alterations); *Dipartimento di Studi Storici, Geografici e Artistici*, Cagliari University (historical studies, archive retrieving, formal reading and interpretation). The system of churches taken in analysis is composed by architectures commonly disseminated all around the Mediterranean area, they are one of the many examples of an European architectural language spreading all around the world and linking the matter of faith to the architectural expression. In Sardinia, in the central part of the Mediterranean Sea, the introduction of the Romanesque architecture assumed very specific and original aspects: it has reinterpreted the church subject according to a mixture of elements with the use of the local geomaterials. This was done with the evident effort to replace the elements of the continental language with the use of local stones. This process brought to rereading the structure of the church according to the particular geomaterials offered by the major island of the *Mare Nostrum*. Between the numerous samples of Romanesque, St. Saturnino, in Cagliari, is a very interesting sample because of the rich stratigraphy of the structures, ranging from the Punic/Roman period to our time, representing a complex combination of elements and materials.

Timeline of the main moments of the Romanesque churches in Sardinia

The story of the Romanesque churches in Sardinia is concentrated in a range of almost three centuries. From the second half of the XI century to the second half of the XIII century: in 1063 Barisone I opens the migration of the monastic orders to Sardinia. A group of monks from Montecassino arrives and adapts to the use of the community the Church of St. Maria in Bubalis. In 1065 Judike Gonnario Comita orders the construction of St. Gavino in Porto Torres, which is indicated as the first Romanesque church in Sardinia. In 1089 Judike Costantino Salusio II starts the transformations on the St. Saturnino Church in Cagliari. This event is a crucial moment for this church, bringing it in the group of the Romanesque churches transforming the previous structures. It is possible to imagine a sort of “influence” coming from the Punic and Roman period and creating a relationship between the ancient ruins and the asset of the new church. Something that brings to an interchange between “new” architecture and previous composition. In the following years, the main events happen in 1107, with the start of the courtyard for the Church of St. Maria del Regno in Ardara. In 1116 there is the completion of St. Simplicio in Olbia. These two works sign the start of the main period of the Sardinian Romanesque. In 1118, the Church of St. Gimigliano in Sestu presents a typical structure with the bell tower placed over the façade. In 1291, the realization of the Church of St. Pietro in Zuri signs the beginning of the last architectural works inspired by the Romanesque. In this period many churches have been built, they are settled all around Sardinia, with a significant concentration around the North-West part of the Island and with a very minor presence on the East coast. The area called “Campidano” has various buildings and all the coast and the inland of Cagliari are rich of well (and not so well) preserved churches from the Romanesque period.

St. Saturnino in Cagliari

The Church dedicated to St. Saturnino has a very complex architectonic story and the events connected to its dedication have the same intricate articulation. St. Saturnino, was originally named St. Saturno, the name was altered into "Saturnino" because of some confusion with the Saint from Tolosa having the same name. This happened during the Spanish domination (1479-1714), thus the iconography of the two saints is very different. St. Saturno (Santu Sadurru) was a young man died as a martyr in 304 A.D. this happened because he was refusing to make a sacrifice to the pagan gods. He had his head cut, but his body was buried in a cave out of the Cagliari town. St. Saturnino (Saturnino de Tolosa) was instead the bishop of Tolosa in the middle V Century, who refused to sacrifice a bull to Giove Capitolino and for this he was linked with a rope to the animal and dragged to death. The causes of their deaths were similar but they are not the same person. The tomb of St. Saturno was placed out of the ancient town, but later the area was included in the expansion of the settlement, and a church was built according to various phases all over the former necropolis. After centuries, in 1621, the body of the Saint was found and moved to the Cathedral, so the place “lost” its main element of devotion. This even tells two things about that time: the place was not considered proper for hosting such a relic; the area, was a place not thought for being preserved.

The evolution of the church can be focused around the following main steps: Its first documented phase takes place in the VI Century A.D. when St. Fulgenzio di Ruspe founds the first convent near a previous basilica. In 1089 there is the arrival of the "Vittorini" monks from Marseille, even if there are no significant remains of their convent, it is possible to imagine some works and transformations of the previous asset. In the XIV century the area encounters a long period of decay. In 1327 with the arrivals of the Aragon’s domination the convent is partially demolished and the area is used as a quarry for other constructions. This caused the partial destruction of the basilica, many materials and parts are used for the construction of the new cathedral. In 1444 the archbishop of Cagliari buys back the area. In 1714 the basilica receives the new dedication to St. Cosma and St. Damiano. Only in the late XVIII century, after various phases of use, abandon, interventions and decay, the area starts to rise interest in historical studies followed by investigations from archaeologists. Later, in 1943, during World War II, it is damaged by the bombs. It has been restored from 1948 to 1952. It closed again in 1978 to start a long restoration courtyard, which finished in 1996. Other transformations followed the reopening, with the construction of a new altar and a new ambo. A new courtyard started in 2010 taking care about the whole area of the lot around the basilica and it is still continuing its activities. The result of all the late restorations have produced a quite strange building, with a mix of old elements combined with a sort of pastiche of architectural parts similar to a collection of solutions and with the absence of a clear global drawing. The building right now suffers from poor environmental qualities (the space of the church becomes very hot in Summer, when the sun exposes the large windows). The large mirror glasses closing the church reflect the reconstructed urban asset made of tall buildings for intensive housing. The last works, still ongoing, are creating massive coverages with grass and Corten iron elements, allowing some kind of visit to the excavation of the area, but completing the transformation of the old settlement in a collection of confused fragments from ancient time to modernity.

The digital survey

The survey of St. Saturnino Church, followed the same structure adopted in the whole research project [COLUMBU S., VERDIANI G. (2014c)]. The survey operations have been conducted here as for all the other 16 churches examined in the project. In the project, to create a referring base for all the information coming form the various units involved in the research, it was decided to create an extended and complete survey of all the accessible interiors and exteriors of the church. According to the general procedures of the project, the digital survey of the complex of St. Saturnino was operated using three different solutions: 3D laser scanner survey, photogrammetry of material samples and interesting artworks and fragments, photogrammetry of a selection of construction materials. The intervention on St. Saturnino was operated in July 2013 and it had a lucky timing, while the courtyard of all the “green” coverages was still not completed and all the area around the church was clear from invasive elements (just some fences here and there and some old coverages). This allowed a high quality view of the complex, something that now is not possible any longer. The survey documented the state of the building with the most of the excavations around the church opened, allowing a good reading of the different levels and of the rich archaeological context.

3D laser scanner survey

The 3D laser scanner survey was done for all the external and internal surfaces of the church. All the accessible rooms were surveyed, the two main guidelines in the definition of the survey campaign were: a) gathering a level of accuracy capable to describe all the main details in the masonry; b) define a complete pointcloud with all the references needed to support and integrate the other surveys and sampling operations. The 3D laser scanner in use was a Cam/2 Faro Photon unit. The scanner showed a level of performance and of practical use highly compliant with the needs of this task. This unit offers good accuracy combined with quite easy handling, it is not a small size scanner (like the new models from the same manufacturing), but it has a reasonable weight and its tripod, even if quite compact, offers a great extension, allowing to reach a point of view higher than the human one. The working range of this instrument ranges from 0.6 to 120 metres. It turned out to be the correct tool for these operations, allowing quick scans when used in the inner rooms and covering the large area of the externals with few scanning stations. The positioning of each scan station was decided according to the shape of the building sector and to its specific conditions. The surveys were always operated in full panoramic mode, exploiting the characteristics of this 3D laser scanner unit, which is capable to scan 360 degrees on the vertical axis and 320 degrees on the horizontal one. At the same time there was the attempt to avoid the over-measuring of surfaces, this was done trying as much as possible to have valid margins of overlap between each scans, but always balancing the density of each pointcloud with the real needs of documentation, which means, first of all, keeping a resolution similar to the accuracy allowed by the scanner. For this reason, using a 3D laser scanner unit with a ranging noise of ±2 millimetres, the planned work was aimed to have an aligned result with an average sampling of 5 to 10 millimetres for all the external and internal surfaces. A series of just 33 scans (22 taken in the external area and 11 inside the church) were enough to cover the whole structure and its nearby area, with all the elements from the archaeological excavation, the open spaces and the presence of few occlusive elements allowed such a low number of scans. The final result, is a balanced and viable dataset, capable to be moved to the subsequent data treatment, but without the need to involve heavy simplification of what has been collected. The final pointcloud is made by 750 million points. To allow fast procedures (the church was completely surveyed in one day) even for the following alignment of the scans it was preferred the implementation of few mobile targets and the recognition of morphologic elements (spots, cracks, signs, small stones, etc...). For this reason it was maintained a certain overlap between each single station and the positioning of the scanner was such to allow the easy recognition of common elements from one scan to the following. All the ancient materials in the church gave a very good response to the laser scanner signal. The only negative exception was caused by the three large mirror glass walls; they caused strong reflections and created ghostly repetitions in some pointclouds. It was quite easy to remove these defects during the post processing of the data and it was the only situation of this kind in the whole project (considering all the surveyed churches). After the completion of the survey the following phases of data treatment were the classical ones: the alignment (done using Leica Geosystem Cyclone), the optimization (with the removal of the “ghostly” parts caused by the mirror windows), the extraction/exporting of data towards other software. One of the first post processing task is the common 2D drawing production: plans, sections and fronts are the typical solutions and in a certain way can be seen as “old” solutions, but they make easy to use, annotate and transfer information because of the well codified language and the easy transfer of the contents between different software. The production of a surface 3D model is right now limited to partial elements, but in the next steps it is planned the realization of a general high quality model for the use in graphical rendering and as a base for digital reconstruction and hypothesis; of multimedia models based on simplified version of the previous; and of partial models for specific use (i.e., analysis, 3D printing).

Photogrammetry of small elements and artworks

Each church has its specific set of unique elements: capitols, decorations, statues, and sculptures are meaningful and useful parts to understand the story and the value of a place. When these elements are worth of a more detailed survey or have an identity worth of a specific 3D model, the choice has been the one to made a specific photogrammetric survey of these elements. This was done to have a superior level of details in front of the one offered by the 3D laser scanner and to speed up the overall operation, separating the detailed survey from the general one, which was optimized for the architectural scale. The photogrammetric survey in St. Saturnino was done using a professional digital SLR, a Nikon D700, with a resolution of 10.3 Megapixel. The camera has a full frame size sensor and was equipped with a Micro Nikkor MF 55mm F2.8 lens, this lens is well known for its quality and the capacity to create very sharp and accurate images. The capacity to reach a minimal distance with the subject made this lens extremely versatile to take images of details. Last but not least the focal length (55mm) of the lens allows a good depth of field stopping down from F8 and has a quite pronounced perspective (similar to the one perceived by the human eye) and this helps the processing in the photogrammetric software. Because of the fact that this lens was originally designed for macro photography, it allows to stop down to F32 with a significant increase in the depth of field, generating a more extended number of usable pixel in the photogrammetric process. To allow a more rational and practical use of the features of this equipment a solid and stable tripod was used for all the shots. The tripod has a double rail macro head, allowing accurate movements and precise positioning of the camera, an useful feature for macro and close range photography. A remote control (to remove any risk of shaking blur) completed the set of tools for the photogrammetric shooting. The software used for all the photogrammetric operations was Agisoft Photoscan, following the classic process of alignment, dense cloud generation, mesh generation, texture generation and, in the end, model scaling according to the data of the 3D laser scanner survey (for the architectural parts).

Photogrammetry of surface samplings

The investigation about the geomaterials has a great importance in this research, so a specific survey of some significant surface sampling was operated in each church. This was done first of all selecting on the wall the most interesting points, a process based only on the experience of the geologist and aimed to find clear decay phenomena and relevant alterations. The idea at the base of this processing was the possibility to “bring away” a very detailed sample of the stone surface without any need to damage the original wall. At the same time, it was formulated the idea to operate a monitoring over these interesting spots. The high level of detail in the survey of the samples gives the possibility to check and verify very minimal difference. Repeating the sampling in time it is possible to hypothesize an accurate check of the ongoing decay and transformation of the surface. The need to locate (and in time to find again) the samples made prefer to adopt an original solution for this part of the survey. It was based on the use of specifically created masks, made to define clear and easily measurable areas, having at the same time markers along the borders to help the identification of the original placing of the sample. The structure of each mask is a square and has a cross shaped hole in the centre, the middle of the cross is 49x49 millimetres in one set of masks, while in the other set it is 24x24 millimetres. In this way it is possible to frame the central area having always at least four points of reference to help putting in scale the final model in Agisoft Photoscan. Almost all the pictures with the larger cross were framed with the whole mask, while in the use of the smaller cross masks the framing was only around the cross itself. The choice of using the smaller or the larger cross was done according to the characteristic of the sample and the “size” of the decay/alteration/phenomenon to be surveyed. The size of the pixel in the photogrammetry made with the Nikon D700 camera when using the large cross masks was around 0.028 millimetres (with a certain range of variation) in the frontal shots. In St. Saturnino the selected samples were 9, 7 from the construction materials and 2 from spolia reused in the construction and probably coming from Roman ruins. Because the small size of the mask it was not possible to use the data from the 3D laser scanner survey to put in scale the masks, but the well-known size of the mask was helpful in resolving this passage. Each mask was numbered and measured again after the survey process to reduce to the minimum the possibility of an alteration in size of the model. A digital caliper was used for all these measurements. Every model developed out of these samples was organized in records with the description of the sample (location, material, a picture with the whole target applied on the wall, a sequence of sections according to the two main axis of the target) for each record an Adobe Acrobat PDF 3D is associated to allow the viewing of the generated 3D model.

Petrographic, geochemical and physical characterization of the geomaterials

In the Romanesque churches of Sardinia it is possible to find the use of different lithologies belonging to the classes of the intrusive and effusive igneous rocks (i.e., granitoids, volcanics) and sedimentary rocks (i.e., sandstone, limestone, etc.) and, subordinately, metamorphic rocks (mainly marbles). The use of these stone materials was not accidental but reflects, on one hand, the opportunities in terms of availability of what the territory was offering and, on the other hand, the intentions of the designer, motivated by stylistic and architectural choices. It also shows a clear link between the use of materials, their availability and the geological characterization of the island [COLUMBU et al. 2011]. Besides the local availability of quarry sites, the choice of lithology was also influenced by aesthetic characteristics (colour, grain, texture, structure, etc.), the physical properties (i.e. density, porosity, mechanical strength, etc.) or by the requirements of purely technical aspects (how easy it was to cut, sculpt, polish the material and its durability) all these factors can be summarized in the word: workability. Because of the wide presence of volcanic rocks all around the Sardinian territory [COLUMBU et al. 2011; Beccaluva et al. 1985], this types of rock have been widely used for various purposes starting from the Nuragic period (i.e. Neolithic) [ANTONELLI et al. 2014; COLUMBU et al. 2013; BERTORINO et al. 2002] up to the Roman period [MELIS & COLUMBU 1998] and in the medieval architecture [COLUMBU et al. 2014a, b; CORONEO & COLUMBU 2010; MACCIOTTA et al. 2001], in all their variable compositions, from basic to acidic (basalts, andesites, dacites, trachytes, rhyolites, etc...). Among those, the ignimbrite rocks were intensely used in the construction of Romanesque churches (i.e. St. Antioco from Bisarcio, St. Pietro in Bulzi, St. Pietro in Zuri, St. Maria in Otti, St. Maria in Castra, St. Demetrio in Oschiri), this choice is due to the excellent workability and variety of colours of these rocks belonging to the Oligo-Miocene volcanic cycle of Sardinia [BECCALUVA et al. 1985]. Their good workability is closely related, in terms of petrographic-volcanological characteristics, to the degree of welding (from medium-low to medium-high) of these volcanics, which allows easy processing and good physical and mechanical resistance at the same time. They were frequently used as building blocks in the masonry walls, as well as in the decorative details. The ignimbrite rock shows a high degree of welding and often was used to construct the first rows of blocks placed at the base of the structure (like in the churches just mentioned), while for realizing the segments of the walls or the architectural elements with particular making (i.e., jambs of the openings, lintels with double conch, sills, cornices and the connection to the roof) it was preferred an ignimbrite rock with a degree of welding from low to medium which presents easier workability characteristics. To interpret and understand the characteristic of the stones and mortars used in the Romanesque churches, a series of samples were taken and analysed from each church (in the whole project the total amount of samples is about 50). The process applied in the laboratory was aimed to the minero-petrographic and geochemical characterization of the geomaterials and to the determination of the main physical properties of the rocks. These analyses, together with 3D laser scanner survey, were aimed to map and to understand the physical decay processes of the monument. At the same time the chemical, macro and microscopic analysis of geomaterials were operated to highlight the chemical alterations and to create the basis for finding their original provenance. The work is articulated in three main phases: in the first phase – activity on monument: macroscopic analysis of geomaterials; identification of alteration forms on the stones; sampling; creation of a link between these information and the digital models coming from the survey. In the second phase the laboratory activities take place: microscopic analysis on thin section (about 30 micron) of the stones; chemical and diffractometric analysis (by XRF and XRD, respectively) of powdered samples; determination of physical and mechanical properties (porosity, density, compression and tensile strength, Point Load Test resistance, etc...). In the third phase all the study activities try to reach a correct interpretation of all the data coming from the first and second phases. In the case of marbles, the various provenances from different quarries in the Mediterranean will be studied using well-established analytical methods [i.e. ANTONELLI et al. 2013]. In the case of St. Saturnino the complex evolution of the site, brings a certain articulation of the materials, with most of the structures presenting homogeneous stone, but at the same time it came out to be mixed with numerous spolia, often made of marbles, but with various blocks in other stones, coming from various locations and quarries, some of them were cut out from a different, original architectural element, others have lost any similarity to their original shape, but are easily recognizable as different from the main stone used for the walls and the vaults. The numerous changes in the church aspect bring some doubt about the original position of these spolia. It is possible to imagine their positioning after works following new constructions or rebuilds. At the same time they testify a particular relationship between the buildings of the site, where in time every previous constructions were seen as something to be used, unmounted, reused and changed according to the need of the time.

Conclusions

At the moment of this writing the treatments of all these data are under development. On a technical level, there is a certain studying about the better way to link the various kind of information to the 3D model. A system of tags putting in relationship the records from the photogrammetry samples to the data from the petrographic analysis seems to be a good solution, but the development of this part of the project is still on the run. The concept around which all the data are going to be organized is the following: the information coming from the research on history and geomaterials will be structured in the form of textual and multimedia metadata, then they will be linked to the models coming from the three phases of the survey. When completed, the models from the photogrammetry works will be linked to the data from the 3D laser scanner, creating an extended base for a further development of specific models aimed to the use for multimedia/dissemination and for research and further analysis. The whole work will be aimed to the definition of a complete and useful base of knowledge for new studies and as a support for the correct restoration of these monuments. In the specific case of St. Saturnino, the total survey puts in evidence some interesting aspects: as it is possible to see in place, the different phases of the building are well recognizable. Taking a look to the scans it is possible to notice how easy is to recognize the traces of the naves demolished and lost as well as it possible to read the articulated stratigraphy of the site. The reading of the survey and the check all over the levels, simply confirm the previous theories about the construction phases of the church. But this easy conclusions, simply underline how wrong is the contemporary architectural approach to this monument. To an intervention aimed to the “showing” it was preferred an intervention of “covering” and where there was the need to simplify the articulation of the elements, new and improper ones have been added. In the end the “new” St. Saturnino shows the positive aspect of a “recovered” place and at the same time the distance between the choices applied and the understanding of the original structure. A bad destiny that seems a constant in time for this site, even if it is a quite strange condition to find after its recognition as a historical monument.

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Fig. 1 – Front view of the main entrance of the St. Saturnino Church, July 2013 (Copyright Giorgio Verdiani).

Fig. 2 – The scanner at work in the St. Saturnino Church, July 2013 (Copyright Giorgio Verdiani).

Fig. 3 – Particular of the glass walls, July 2013 (Copyright Giorgio Verdiani).

Fig. 4 – Images from the new interventions, June 2014 (Copyright Francesca Rossi)

Fig. 5 – "Panchina tirreniana" sandstone. This stone, which in the outcrops varies from sandstone to conglomerate, belongs to the Tyrrhenian (i.e., chronostratigraphic unit of the Upper Pleistocene, Neozoic). It has been used in the basilica of S. Saturnino with a minor extent than the Miocene limestones from the formation of Cagliari (i.e., "Pietra forte" and "Pietra cantone"). In the photo it is possible to see the alteration differentiated between the matrix, crystalline granules and fossils fragments (mainly residues of seashells), where these latter are enucleated for dissolution processes on the surface of the carbonate matrix (Copyright Stefano Columbu and Giorgio Verdiani).

Fig. 6 – "Pietra forte" limestone. This stone is a compact and resistant rock and belongs to the Messinian and also to the Tortonian (i.e., chronostratigraphic units of the Miocene, Cenozoic). Together with "Pietra cantone" stone it has been largely used in the basilica of S. Saturnino, more than all the other lithologies. In the photo it is possible to see the characteristic primary porosity (mainly closed in the matrix) due to the presence of fossils and other elements (Copyright Stefano Columbu and Giorgio Verdiani).

Fig. 7 – Marble from the spolia of a Roman column placed in the basilica during the Romanesque period. This stone shows evident surface alteration with strong decohesion and fine exfoliation (Copyright Stefano Columbu and Giorgio Verdiani).

Fig. 8 – Volcanic stone. This rock belongs to the first important volcanic cycle in Sardinia (32-11 Ma; Beccaluva et al. 1985), probably it is a Roman ashlar coming from the Punic-Roman city of Nora (South Sardinia) and re-used in the basilica during the Romanesque period. In fact, the territory around Nora presents outcrops of the same volcanic stone while in the territory of Cagliari this rock is not present (Copyright Stefano Columbu and Giorgio Verdiani).

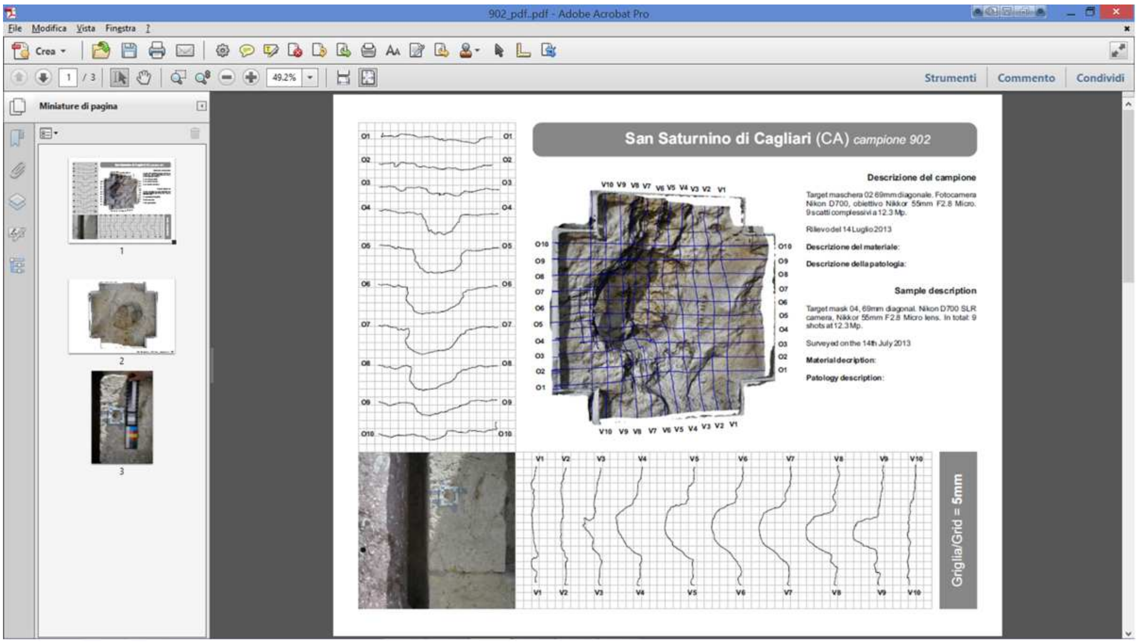

Fig. 9 – Record from one of the constructive material samples (Copyright Stefano Columbu and Giorgio Verdiani).

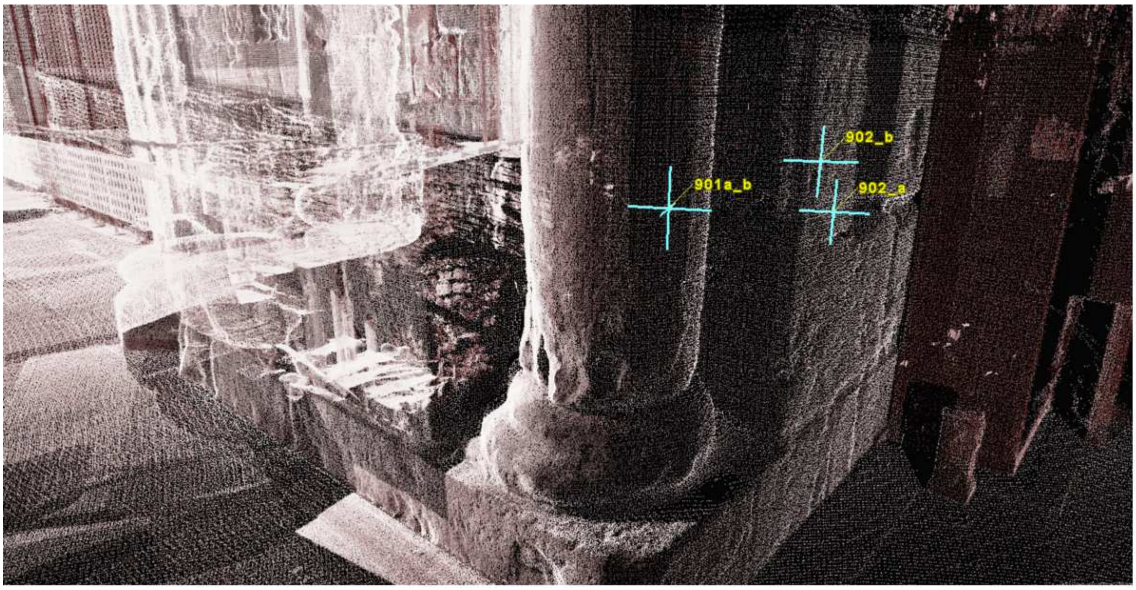

Fig. 10 – The records brought back as tags inside the aligned pointcloud (Copyright Stefano Columbu and Giorgio Verdiani).

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