*Matera, modification: cut*

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# In situ experimentations for the compatibility and durability of the restorations: the case study of the Sassi of Matera.

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## ABSTRACT

The research intends to make a study of the interventions of restoration realized in a sample area, ("Sassi of Matera"). Aiming to establish an operating methodology with interpretative and implementable rules for the assessment of the concept of durability and service life in recovery interventions, starting from the preliminary phases of intervention and therefore from the project.
It is intended, in particular, to assess durability of the recovery intervention, analysing the aspects of subject compatibility, performance harmony and programmed maintenance. Starting from an initial check based on validation of the choices made through on site experiments, laboratory tests respecting the current regulations, and from predictions of the useful life of the used components, technological and subject compatibility and maintainability of these components. The objective is to formulate implementable technical intervention sheets which are an indispensable means for intervention planning and programming.
Underline that durability of interventions must necessarily undergo the control and mastery of the traditional building techniques and a "programmed" design that is coherent with such interventions, guaranteeing a linguistic continuity of the landscape of the Sassi between its past and future, humbly respecting an environmental heritage of great value.

## KEYWORDS
*durability, compatibility, experimentations, traditional and innovative materials, recovery project*

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## 1. INTRODUCTION

In the past, the building was characterized by a strong link with its place of construction, determined by the use of local raw materials and the adoption of technological solutions aiming to control the climate and environmental variables as well as by the use of recognizable cultural forms. In the Mediterranean areas, it is easy to see how, although in different forms, all buildings constructed until the last century have high bio-climatic performance and are based on local materials.
In this historical context, before performing recovery works, it is necessary to set up the specificities of the project, namely to define the activity field, the interrelations, the autonomy and the complexity of relations with the entire environmental system. In addition, once identified the interventions to be carried out, the materials must be chosen according both requirement of compatibility (utilization phase) and durability (cycle of life).
On the other hand, since any human intervention, as correctly planned as it might be, inevitably leads to a change in the environment, it is necessary to ensure, from the initial planning phase, that such changes allow new acceptable equilibriums to be established and that using the resources will not compromise the reproduction capacity. An assessment of the different components must be integrated into the general planning procedures of all the work that is likely to alter the initial environmental conditions considerably because of its nature or the characteristics of the area in which the work is to be carried out. From this point of view, the research intends to define a methodological approach to identify interpretative and implementable rules to assess the concept of durability in restoration interventions.
The complex of Matera's Sassi is particularly interesting in terms of bio-eco-compatibility. Indeed, it allows to concretely verify the possibility of recovering according to the nature of the sites, using materials, construction techniques and technologies compatible with the pre-existing constructions. However, the intervention project must be preceded by an appropriate diagnostic campaign and by laboratory and in situ testing as well.
The need to find out a single planning methodology arises from this, in order to control the approach to the intervention by regulations. This methodology is easily dividable into three larger phases capable to synchronize the entire operative course of action,

Figure 1.

*Matera*

from the idea of execution to the intervention, as well as the management of the intervention work being undertaken.

## 2. THE SASSI OF MATERA

The city of Matera[1] consists of several cores that mark the different moments of its history. It is a very ancient inhabited place where it is easy to see the signs of man, from its origins until today. The city is universally known for its exceptional historical center, especially for the two Sassi's urban layout, one of a kind, a UNESCO heritage site since 1993.
The first human settlements on the Matera's karst terraces are attributed to the Paleolithic and Meoloitico as evidenced by numerous archaeological findings. During the Paleolithic, the men use the caves and natural ravines carved into the rock as a refuge. Later, they began to prefer higher sites with natural fortifications and possibilities to control the surrounding territory. For this reason, a prehistoric village developed on the spur of the Civita, gradually assuming "*proto-urban*" dimensions and characteristics (Rota, 1990). For over a millennium, until the Middle Ages, this was the form of the city: the fortress of Civita at the top and small villages and groups of inhabited caves along the slopes of the ravine. The city has always been divided into two parts: at the top of the hill of Civita, protected by walls and towers, and at the bottom, along the two steep valleys, the two districts called Sassi, whose dug dwellings are perfectly camouflaged with the surrounding environment. In addition, the two steep valleys were demarcated and defended by natural ditches called *grabiglioni*[2]. This scheme was maintained over the centuries and outlined the urban development of the city. The Sassi, as we see them today, are the result of a slow and gradual process of transition from exclusively rural life forms to semi-rural and urban forms.
Since the seventeenth century, with the increase in population, the highest part of Sassi, close to Civita, was beginning to be affected by construction of new houses and palaces.
A consumption mechanism was grafted in the two Sassi, which determined a loss of all positive values and infrastructures in the constant random search for new housing areas. The free areas that were once filled by the little vegetable gardens, which previously characterized the semi-rural appearance of the Sassi were lost and all of the areas, which were designed to serve the houses (wells, stalls, "nevere" [type of fridge], cellars and rupestral churches), were transformed into new houses with substantial adjustments.
During this period, the city, formed over the centuries on an extremely rugged site with a singular orography, regresses in both social and economic conditions and in residential terms.
This situation of degradation and poverty, with its tragic social consequences, continued until the middle of the last century, coming to an end with the mass desertion and depopulation of the two quarters of the Sassi, occurred between 1953 and 1968 (Rota, 1990).
Special National and regional laws for the Sassi followed the beginning of the 20th century and finally ended in 1986 with the last special law (the preservation and recovery of the Sassi quarters of Matera) and the approval in 1988 of the first two-year program for intervention in the two ancient quarters of Matera.
Because of these special laws and the inclusion in the UNESCO world heritage, the Sassi are currently subjected to a complex restoration and recovery action.

## 2.1 TERRITORY AND ARCHITECTURES

The Matera territory is crossed by a deep incision, the Gravina Torrent, and the city develops on the upper part of the right side of this creek.

Figure 2.

*Matera and Gravina*

This territory develops in the transition area between the Murgiana platform, the Apulo foreland and the Bradanica foredeep. In fact, it is characterized by outcrops belonging to the two geological domains:

1. the limestones, which are part of the Limestone Group of Murgia, also known as limestone's of Altamura[3], and which constitute the substrate of the entire region;
2. The Calcarenite of Gravina[4] that occupies the top layer (Casagli, 2002).

In the area of the Sassi, the stratigraphic clearance between the layers of limestone and calcarenite occurs at a variable depth between 350-360 m, with the interposition of a third layer, much more coarse, called calcirudite, that reaches a maximum thickness of 2 meters.
The thickness of the calcarenitic rock mass significantly increases from the edge of the Gravina towards the inside, passing from a few meters up to a maximum of 60 m, and is within this layer where the first Matera houses have been excavated.
The originality of the morphological configuration of this settlement is due to its development along the steepness of the edge of the ravine, to the substantive changes made by man over the centuries, to the hydrological characteristics and to the action of weathering as well.
This type of city is strongly linked to the relationship with the calcarenitic mass that constitutes the basic element of the buildings. In fact calcarenite, which offers digging precision and satisfactory guarantees of geo-technical stability, has enable new caves to be added to the natural, existing ones, treating the excavated part according to the same formal schemes of the built architecture.
Moreover, calcarenite, in addition to preserving the dug interior by significant water infiltration, allows the temporarily flowing on the surface of the rainwater, which gazes on the natural fractures of the rock and then is collected in several tanks with the typical bell shape of the Sassi dwellings. This urban plant, punctuated by a succession of fluvial or man-

Figure 3.

*View of the dwellings of Sasso Barisano*

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made terraces, is articulated by means of a vertical succession of levels, sometimes excavated or partly excavated and partly built, the number of which varies in the districts on the basis of the original shape and height of the calcarenitic slope. It follows that, while there are only three levels in the Malve district and six up to twelve levels in the Civita neighborhood.
The caves, which open in each order of terraces, are set side by side and branch out, intersecting in the most varied ways. They are characterized by various forms and a planimetric evolution, which is sometimes extremely irregular. They are clearly fixed from time to time during excavation works and imposed by the variation presented by the calcarenite in the degree of cementation (Guida, 2005).
These caves are dug obliquely into the ground. In this way, the sun's rays penetrate to the bottom and natural ventilation takes place. Often these caves-dwellings looked out of the same space, the *vicinato*; a kind of common courtyard where many of the daily activities were carried out. The *vicinato* was a real urban cell of relations and mutual assistance in which the private space was to merge to coincide with the public one.

The Sassi architecture typological schemes come from the cave-house, a space set out by two parallel walls and an arched ceiling, a final wall made up of a mass of rocks and the façade made up of tufa blocks, in which there is only one door with a fanlight to light and ventilate the environments.
The cave-dwelling was enlarged by digging in the calcarenitic rocks, but also with a type of building, called *lamione*[5], which extends the cave towards the outside. The *lamione* reproduces the morphology of the hypogeal dwelling, showing off through the form of the building above ground the original cave, thus the matrix of each housing type.
The *elementary basis* we find even in the most developed houses, palaces and high-class architectures, built in later times with respect to the first housing-settlement in the Sassi.
This points out the *building structural regularity*, constituted by a single material, the tuff; everything is made of blocks of tuff, from small decorative elements to the partitions of a house until the entire urban aggregate (Giuffrè, 1997).

Figure 3.

*View of the dwellings of Sasso Caveoso*

Figure 4.

*The Civita*

## 3. THE CALCARENITE, A CONTINUOUS DEGRADATION MATERIAL

### 3.1 CALCARENITE

The stone mainly used in the construction of the Sassi is the so-called "Matera tuff", a tender rock, which is easy to work, which physical and mechanical characteristics are of increased or decreased resistance depending on where the rock comes from and where it is extracted.
The calcarenites are soft and porous detrital rocks constituted of at least 50% by limestone granules with organic and /or inorganic origin, immersed in a calcitic cement and/or in a fine-grained6 limestone matrix. These materials have colors ranging from yellow to gray-white and reveal the presence of macrofossil in sedimentation layers
An important feature of the calcarenite is the variability of its granulometric assortment and of its degree of diagenesis. The particle size ranges from medium-coarse to medium-fine, so from a material with a stone consistency to another one with the characteristics of a sandy soil, weakly cemented, which can be fractured with a slight pressure of the hand. The differential erosion, which hydro-weathering agents operate on the rocky surfaces, accentuates this property (Cotecchia, 1975).
The use that was made of this rock tended to enhance these special features; in fact, the blocks with a harder and more compact appearance were used for the layer of foundation to support the loads from the upper walls and to oppose increasing resistance to the capillary uplift of the water in the ground; in other words, they were used to create architraves for the doors and windows or to create the steps of the external stairways to access the houses and for greater resistance to wear and to atmospheric agents.

### 3.2 THE DETERIORATION OF THE WALLS

Construction in the Sassi is almost exclusively made with calcarenite. Thus, knowing the physical characteristics of the compressive strength of this material means to know the possible causes of instability and degradation present on it.
The degradation of calcarenite, for chemical

**Figure 6.**

*Alveolization of calcarenite*

**Figure 7.**

*Hypogeum with moss and lichen*

causes (eg. The dissolution of $CaCO_3$), produces a remarkable drop of the physical characteristics and mechanical strength of the construction elements, with consequent sagging and breakage, which occur with greater frequency in the areas in which these homes are still in a state of abandonment.
But the main degradation is due to the presence of water, poor ventilation and weatherability, and they are manifested in the form of black crusts, runoff of surfaces, alveolization, microbiological alteration, saline efflorescence, mold and lichens.
The dissolution of calcium due to acid rain occurs on the outer surfaces. This phenomenon causes a further increase of the porosity. The condensation phenomena occur on the repaired surfaces and, by depositing of the particles suspended in the air, they form black crusts, which are cemented by recrystallization of the external calcium carbonate. The alveolization phenomenon is linked to the presence of runs, produced during the processes of sedimentation of calcarenite, filled with mud. It is caused by the internal movement of the moisture, which causes the crystallization of soluble salts with the consequent phenomenon of efflorescence. This phenomenon is also accentuated by small eddies that the wind creates into the already formed cavities causing an effect of mechanical abrasion by particles suspended in the air. Another widespread degradation, present both inside and outside of the hypogeal environments, is the microbiological alteration that causes darkening of the wall, and the proliferation of mosses and lichens. So on the internal and external facades of the Sassi is likely to get these phenomena both separately and jointly with the superposition of the effects.

## 4. THE PROPOSED INTERVENTION

Interventions' durability is linked to the response of the new elements' disposal when becoming integrated both dimensionally and functionally in the pre-existent building according to a particular service program, therefore according to a suitable compatibility. Considering the Sassi of Matera's values, the intervention suitability is not only the efficiency procedures choice of the required services, but it becomes a precise study about the customer's needs and the possible technological choices in

Figure 8.

*Compartment subject to intervention*

order to satisfy them coherently with pre-existent's architectural features. For the shape, typology and structure of the Sassi of Matera, the research has concerned the durability assessment in recovery interventions, carried out or going to be carried out on the tufa wall with its trimmings (Guida, 2007). The intervention aimed at the restoration of the Sassi must be understood as a quality research in the transformation and renovation of the recovered heritage. This can only be done by applying already proven operational methodologies, technologies and processes monitored scientifically. Primarily, Some technological tests have been carried out. They were intended to settle the physical, chemical and mechanical features of the materials used in the Sassi houses' (tufa, mortar, plastering) in order to assess the used materials' (physical, chemical and mechanical) compatibility. If necessary, it is possible to use new materials during restorations and also for the choices carried out during the interventions, as in the case of using a specific inorganic reinforcing agent of the rocky mass or typical dehumidifying plastering. In effect, the reinforcement and restoration interventions of these environments are conditioned by the strict regulations that require one to use products that don't cover the walls and that don't alter their color, leaving the environments intact and thus, with all the exterior characteristics of the walls unaltered. Plaster can only be used on interior walls. Numerous laboratory tests have been carried out on specimens taken from the materials in the sample area (compartment Rupestrian Habitat). These tests have allowed us to know the chemical and physical properties of materials and to determine their mechanical characterization.

Building upon the achievements of the performed analysis, an experimental activity in the laboratory was carried out with the intent to improve the characteristics of calcarenite drawn from hypogeal structures through the application of consolidation. The hygienic restoration of the underground structures in the Sassi of Matera present notable difficulties due to the extent of the environments to be restored. In fact, in these cases, a need for intervention on the entire wall has been demonstrated, due to the humidity caused by being in constant contact with the rest of the tufa that lines all of the underground walls. It is paramount that the treatment guarantees the walls have good "perspiration" in order to avoid the formation of superficial layers that could, over time, break-off when under pressure from the water present in the walls to be treated. A product that helps to stop humidity in the walls must be used, slowing down perspiration and eliminating eventual water residue on the walls. This can be achieved through thermo ventilation and forced air exchange. The underground walls act as a sort of "sponge", consequently with a sort of "*drainage effect*" that once dried, reabsorbs the water present in surrounding areas, which is then in turn given off as humidity into the environment (Guida, 2013). The solution to the problem clearly lies in the intervention of the regulation of both the amount of water as well as the speed at which it is taken from the walls. A lab experiment was carried-out on various samples of limestone taken from some underground


Figure 9.

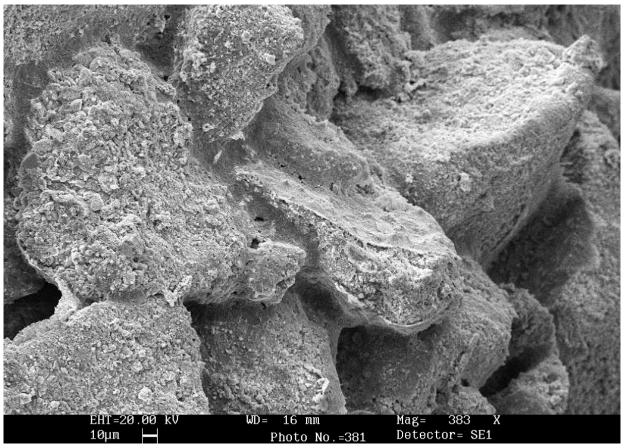
*Planimetry of the compartment subject to intervention*

environments being studied, which were treated with a stabilizing material. An inorganic material with specific characteristics that are well suited to the needs of the site was used for this experiment: reinforcement that doesn't impede the characteristics of the limestone, that is suited to the chemical structure of the base material (limestone), that allows the limestone to maintain its porousness, that is very durable, not very invasive and which doesn't alter the natural color of the rock. The main active ingredient of the product used is a mixture of soluble Aluminium. The property of reinforcement is due to the formation of an Aluminium gel, which moves into the pores of the stone, creating a type of electrostatic interaction that increases internal cohesion, and reduces crumbling. Experiments brought about the decision to use products with a Lime base (P.C.), an Aluminium base (P.A.) and a Silicon base (P.S.).
The results obtained have been confirmed both by visual comparison as well as using images from electric scanning microscopes, of all samples. The best mixture used for intervention was the P.S. one, in fact, it has the best response in terms of density, porousness and variation; the best visual impact, in the almost unaltered coloration of the rocks; in the net improvement of the technical characteristics.

Aside from the results obtained from the following experiments, the choice to use the P.S. mixture and not the other two for reinforcement is due to a prediction of greater durability for the intervention, because such a product has the same base composition as the original rock and hypothetically it should have the same degradation. After having evaluated the results of the application in the laboratory, the same consolidating was also applied in situ, where obviously the environmental conditions are much more variable than those recreated in the laboratory. After just a few months from the application and with the only visual monitoring, the result of in situ experiment seems to be comparable to that one obtained in the lab. We are making a constant monitoring in order to assess effectively the durability and the degradation processes.
The same campaign of technological tests was performed on samples of plaster used in previous interventions of restoration, but already strongly degraded. The results of the analyzes carried out show that the main cause of deterioration is due to the presence of water by capillarity or by direct contact with calcarenitic boulder. This phenomenon occurred shortly after the completion of some restoration works when plaster was used with a binder matrix based on

Figure 10.

*Section of the compartment subject to intervention*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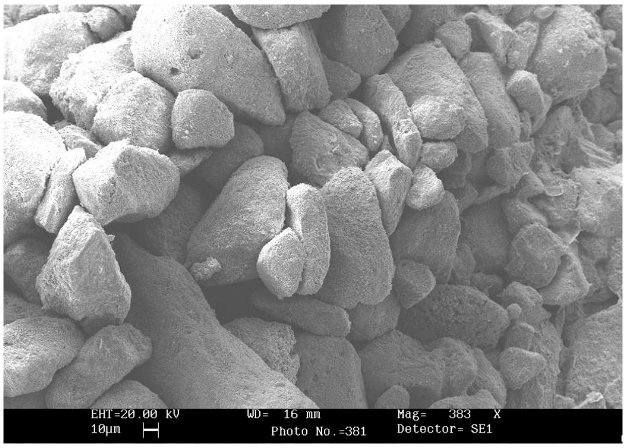
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lime and cement. This type of mortar was found to be slightly porous, or with non-homogeneous porosity, and in any case not sufficient to accommodate the salts crystallization, and it was as well little permeable to water vapor.
In these cases, the use of macroporous plaster is particularly suitable. They have macro-porosity that allows the elimination of the humidity by water evaporation. They are compatible with the existing masonry because they are less rigid than cementitious ones. They have a elasticity module similar to the historical mortars or however comparable with those of the substrate. Finally, they offer greater resistance to the action of the disintegrant soluble salts.
At this point, we have tested in situ two types of macroporous plaster of two different manufacturers. The plasters were applied for small samples with identical dimensions on the same wall at the same site, so with the same environmental conditions.
The first qualitative and visual feedback were done limited to the scope and to the short time observation (just a few months). Between the applied products, Terrasan Calcideis the one having less alteration ant not having stains and traces of efflorescence. Again, after the experimental activity, following the indications of the producing sheets, the macroporous plaster that gave the best results was used extensively in some parts of Sassi during a restoration.
Upon completion of the experimental phase, we have identified the useful parameters to define the reliability, durability and compatibility of the materials, in order to define the "maintainability" and "life cycle" of the individual components and/or the entire intervention recovery.
These requirements, classified also as a function of their effects with a typical downward trend, highlight the advantages, limitations and possible intervention alternatives, selecting the most compatible and reliable material with a longer service life related to the specific recovery target. Thus, in order to obtain a global assessment of each intervention, data sheets were drawn up.
These summarizes the characteristics of the used materials, the causes of deterioration and diseases,

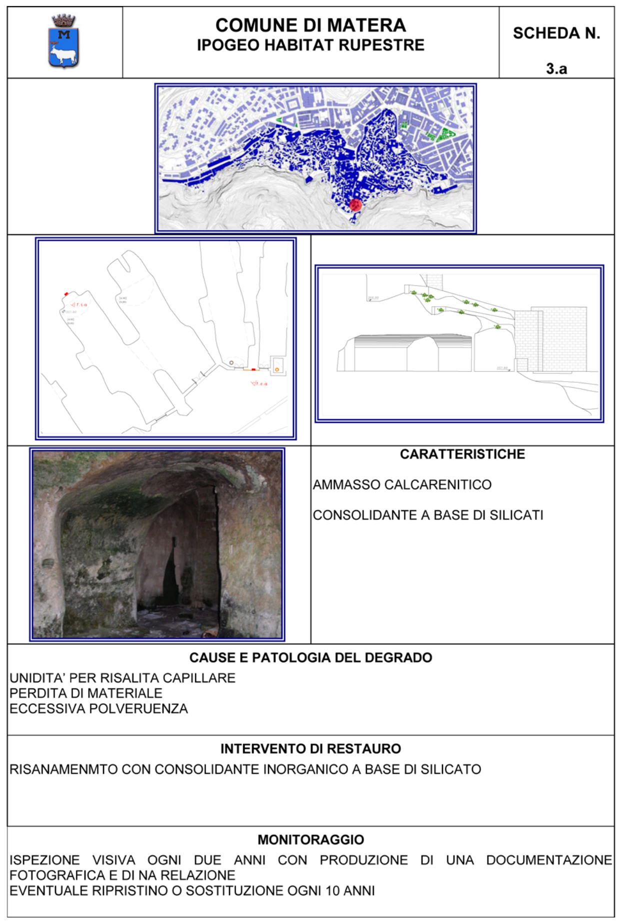


Figure 11.

*Sample treated with P.S.*

Figure 12.

*Electron microscope images after consolidation with P.S*

Figure 13.

*Electron microscope images after consolidation with P.S.*

Figure 14.

*Application of macroporous plasters*

Figure 15. 16.

*Inside of the Hypogeum after recovery with application of P.S and macroporous plaster*

Figure 17.

*Data sheet of the Hypogeum after recovery with application of P.S.*

| COMUNE DI MATERA<br>IPOGEO HABIATAT RUPESTRE | | SCHEDA N.<br>3.b | | |
|---|---|---|---|---|
| REQUISITI DI AFFIDABILITA' | | | | |
| | | Buono | Suff. | Scarso |
| 1 | Stabilità | ■ | □ | □ |
| 2 | Benessere termico-igrometrico | ■ | □ | □ |
| 3 | Adattabilità e funzionamento in esercizio di finiture e organi meccanici | ■ | □ | □ |
| 4 | Aspetti degli elementi tecnici | ■ | □ | □ |
| 5 | Funzionamento globale di subsistemi e componenti | ■ | □ | □ |
| 6 | Integrabilità degli elementi tecnici | ■ | □ | □ |
| REQUISITO DI DURABILITA' | | | | |
| | | Buono | Suff. | Scarso |
| 1 | Resistenza meccanica | ■ | □ | □ |
| 2 | Resistenza all'usura | ■ | □ | □ |
| 3 | Anigroscopicità | □ | ■ | □ |
| 4 | Stabilità morfologica | ■ | □ | □ |
| 5 | Stabilità termica | □ | ■ | □ |
| 6 | Stabilità chimica | ■ | □ | □ |
| 7 | Tenuta all'acqua | □ | ■ | □ |
| 8 | Resistenza agli agenti atmosferici | □ | ■ | □ |
| 9 | Resistenza agli agenti chimici | □ | ■ | □ |
| 10 | Resistenza agli agenti biologici | ■ | □ | □ |
| 11 | Resistenza al gelo | □ | ■ | □ |
| 12 | Resistenza all'irraggiamento | □ | ■ | □ |
| 13 | Resistenza allo sporco | ■ | □ | □ |
| REQUISITO DI COMPATIBILITA' | | | | |
| | | Buono | Suff. | Scarso |
| 1 | Dimensionale | ■ | □ | □ |
| 2 | Meccanica | □ | ■ | □ |
| 3 | Fisica | ■ | □ | □ |
| 4 | Chimica | ■ | □ | □ |
| REQUISITO DI MANUTENIBILITA' | | | | |
| | | Buono | Suff. | Scarso |
| 1 | Controllabilità e facilità d'intervento | ■ | □ | □ |
| 2 | Pulibilità | ■ | □ | □ |
| 3 | Riparabilità | ■ | □ | □ |
| 4 | Sostituibilità | ■ | □ | □ |
| NOTE<br>VALUTAZIONE DEI REQUISITI SU CAMPIONI PRELEVATI NEI SITI INDIVIDUATI, MA TRATTATI SOLO IN LABORATORIO | | | | |

Figure 18.

*Data sheet of the Hypogeum after recovery with application of P.S.*

timetables and monitoring instruments and especially the satisfaction or not of the requirements of reliability, durability, compatibility and maintainability, through the respective compliance (good, fair and poor) of the carried out intervention.

The above described data sheets of restorations are important to verify the chosen procedure and to subsequently validate the intervention with the satisfaction of the listed requirements.

## CONCLUSIONS

The retrieval and change process of a historical area such as the one of "Sassi of Matera" and however of every historical built context, requires, without any doubts, a particular focus on all past memories as regards traditional building techniques and processes. And whereas such memories meet, it is possible to start some experiments of what today is the applying technical luggage related to the construction and building retrieval field. Welfare problems, comfort, applicability of modern materials, firmness and features of basic materials and the durability of occurred interventions, represent the 1st step for a careful technical planning analysis aiming to reconversion, and an aware retrieval of architectures and historical cities.

Intervention monitoring and experimental sampling of historical materials will allow to acknowledge faithfully how materials and building techniques must necessarily act as mediators and at the same time it will consider alternative, innovative and more sophisticated techniques as examples, in order to keep a good compatibility between past and present. And it is only by considering the impact of modernization on an ancient context such as this, that the subject of intervention durability will necessarily pass through the control and mastery of traditional building techniques and a "programmed" design, in keeping with such interventions. The objective of the intervention must be to guarantee linguistic continuity of the landscape of the Sassi between its past and future, humbly respecting an environmental heritage of great value.

## NOTES

1. Matera is the second most populated city of the Basilicata (Southern Italian region). On 17 October 2014, it was designated, together with Plovdiv, as European Capital of Culture 2019 Matera.

2. The grabiglioni had torrential regime and were powered by runoff water from the hills above. In the last century, these two grooves have been transformed into two major arterial roads: Via Fiorentini (Sasso Barisano) and Via Buozzi (Sasso Caveoso).

3. The limestone of Altamura consists of a monotonous sequence of compact, laminated and micriticlimestones that are well-stratified and intensely fractured; they present planes of arrangement variable, but predominantly dipping, with an angle of 5 ° - 10 °, toward the southern quadrants.

4. The Calcarenite of Gravina is constituted by both bioclastic and lithoclastic calcarenites with a grain variable from silt to gravel. These calcarenites, cemented and thickened to a varying extent, are stratified into large layers in horizontal position or slightly inclined and dipping.

5. The Lamione, in its essential form, is made by the extension outside of the barrel vault, the carrier of the hypogeal home, supported by massive stone side walls and closed by a third wall where there is the entrance door.

6. The three elements making up the rocks are generally skeleton, matrix and cement. Skeleton usually consists of lithic fragments of pre-existing limestone and fossil residues of various types of organisms. The greater or lesser predominance of each one over the other one characterizes its compactness. Matrix, in case it is of carbonate kind, consists of tiny fragments of the constituents of the skeleton with minute aggregations of calcareous cement. The greater or lesser presence of matrix reduces the voids and improves the mechanical behavior of fragility. Cement occupies all the cavities left free by the other two elements. Its quantity and quality increase the strength values of the material. Normally, in calcarenitic rocks it is of carbonate kind with various morphologies.

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