Environmental Monitoring of the St. Gennaro and St. Gaudioso catacombs in Naples
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1. Introduction
A progressive improvement of the strategic approach to the conservation and protection of the heritage of historic centers, allows the experimentation of methodologies and tools to assess the choice of enhancement of the architectural heritage [Viola S., 2012, 35]. The knowledge phase makes it possible to identify the cultural heritage’s intrinsic potential to exploit and create a framework supporting information in the decisional phase of recovery. The basic theoretical assumption will be based on the knowledge of behavioral and evolutionary dynamics of endogenous and exogenous construction that are essential characteristics in any safeguard strategy. The instrumental diagnostics plays the role of support in the definition of these dynamics, giving measured data to support the theoretical point of view. The diagnostic is therefore used to evaluate microclimatic environmental conditions in order to have a framework in the evaluation of the degrade phenomena [Caterina G., 2003, 28]. The acquisition of the experimental data and its subsequent processing enables to build a knowledge model of high reliability. It can be realized with a mobile laboratory, which allows to measure the environmental parameters in situ. To carry out an experimental monitoring campaign for the air quality assessment a pathway was designed in order to investigate about contaminants and analytical parameters with the aim to recognize the developing processes of the decay.
Urban air pollution significantly affects the climate, human health and the state of conservation of the architectural heritage.
In this study, the environmental parameters measurement in the Neapolitan Catacombs, are reported. In particular CO₂, temperature, humidity, pressure and radon gas concentration measurements were carried out.

2. Materials and Methods
2.1. Catacombs¹ description
The numerous underground cemeteries of Naples are spread around the neighborhood “Sanità-Vergini” traditionally called the Valley of the Dead. The object of this study are the ancient Catacombs of St. Gennaro and St. Gaudioso, dated back to the second century, the ideal sites for the construction of large underground tunnels thanks to the good quality of the tuff. These catacombs extend horizontally covering large areas because of the peculiarities of the Neapolitan yellow tuff: a compact, durable and porous stone, very easy to work. The catacombs of San Gennaro are structured in two levels, non-over-
lapped, developed side by side and connected to each other by an external walk which substitutes the antique steps built to let people pass from Basilica Maior to the Vestibulum Inferior leading to St. Gennaro’s tomb. Therefore they are called St. Gennaro Superiore and St. Gennaro Inferiore. The guided tour through St. Gennaro Superiore catacomb extends on 135 m, the catacomb of St. Gennaro Inferiore extends on 100 m and they are the results of the union of different sites built in different times. The catacombs of St. Gennaro Superiore and Inferiore constitute a single guided walking tour of 60 min, while the guided walking tour of St. Gaudioso lasts 50 min. The catacomb of St. Gaudioso extends on about 100 m. In all three catacombs the air temperature is between 16 – 19°C all year round and the air humidity is 97 – 100 %. They are plenty of cubicula², arcosolia³ riched by many frescos and mosaics with allegoric meanings in Christian iconography which collected Latin and Greek iconographies. The pictures of the three catacombs are shown in figures 1-3.

2.2. Mobile Laboratory for environmental parameter measurements
The measurements are the result of a collaboration between the Laboratory of Reuse, Rehabilitation and Maintenance of the Architecture Department (LRRM) and the Radioactivity Laboratory (LaRa) of Physics Department of University of Naples Federico II. The monitoring has been carried out in accordance with the experimental procedure for measuring environmental parameters, included in the Maintenance Plan, that is the subject of the Quality Certification (UNI EN ISO 9001-2008) “Procedures and operational tools for building maintenance. Environmental conditions and the built heritage in the historic centers”, implemented by “Quality Centre of the University Federico II”. LaRa belongs to Quality Management System UNI EN ISO 9001-2008 implemented by “Quality Centre of the University Federico II” concerning the “Measurements and tests activities in field of ionizing radiations and dosimetry”.

2.2.1. Babuc measures
In order to estimate the obsolescence and decay processes inside the catacombs, some parameters were identified:
- thermo-hygrometric parameters;
- parameters anemometer (air velocity, turbulence);
- chemical parameters (carbon dioxide, sulfur dioxide).
To measure the environmental parameters, a mobile laboratory is accomplished by the use of a multichannel device for the acquisition of chemical and physical parameters (BABUC) in order to define the air quality. It is used to capture, display, store and process the physical environmental parameters. It consists of a small electronic unit data acquisition. The probes for the assessment of the environmental quality are:
- temperature probe, which measures the temperature of the air;
- psychometric ventilated probe to measure: dry temperature, wet temperature and relative humidity. The probe is produced in accordance with ISO 7726 “Thermal environments - Specifications Relating to appliances and methods for measuring physical characteristics of the environment”. It consists of two
temperature sensors: the first measures the dry bulb temperature of the air and the second, covered with a sheath hydrophilic kept wet with distilled water in a pan, measures the wet bulb temperature with forced ventilation; - anemometer probe, which measures the speed of the air at high resolution, the intensity of turbulence of the air, the air direction. The detector is a platinum wire. Its temperature is kept constantly higher than external temperature by an electric current flow. This current intensity allows to calculate the air speed; - probe to measure the pollutant gases concentration is composed of a cell absorption with infrared sensor that analyzes the air at the wavelength of absorption of the gas.

The picture of these probes is shown in the figure 4.

They are aimed at verifying the fruibility of places, depending on the conservation of the architectures affected by decay, in relation to the concentration of the other pollutants. The experimental procedure depends on the object to investigate, on the physical phenomena to be measured and on the type of monitoring to be improved. It consists of the following steps: identification of the area object of the environmental monitoring, feasibility check, indication of the perimeter and the area, identification of the points in which to perform the measurements, the frequency of measurement, the identification of the data recorded at intervals of 15 minutes during 24 hours, the selection of probes, setting the parameters of the Babuc M and starting measures, data acquisition, data download on the PC, evaluation and processing. The experimental procedure allows to detect the underground environmental conditions and quality through the analysis and evaluation of the presence and movement of contaminants, affected by the high rate of humidity and temperature ranges.

2.3. Radon risk for guides

Since 1988 WHO (Word Health Organization) by IARC (International Agency for Research on Cancer), has classified radon in Group 1 carcinogen together with asbastos and smoke[IARC, 1988, 173]. Many countries have developed very strict laws to regulate the levels of carcinogens, including radon (222Rn), allowed in the workplaces. Many epidemiological studies have proved that permanence in environments with high concentrations of radon and its short-lived decay products increases the risk of developing lung cancer. Radon originates from the decay of radium 226 by α- emission in the natural chain of uranium (238U). It is a noble gas with several isotopic forms, 222Rn is the longest-lived isotope with an half-life of 3.8 days and decays to a sequence of short-lived radionuclides called radon decay products, radioisotopes of heavy metals: polonium 218Po, 214Po, lead 214Pb, bismuth 214Bi. In confined environments radon can accumulate reaching dangerous concentrations because of the low ventilation which causes a build-up of radon and its decay products. Underground workplaces like mine, cellars, caves and catacombs, are characterized by a high radon rate emanating and exhaling from the rocks as well as by environmental parameters such as temperature, humidity and pressure [Abdelzhaer M., 2011, 749]. In fact, radon concentrations in underground are affected by outside-inside temperature, differences of atmospheric pressure.
and ventilation rate. Moreover, the geological and morphological structure of the sites also influences the radon concentrations.

Italian regulation D.Leg. 241/2000 imposes the control and monitoring of radon concentration in all underground workplaces [Italian Government, 2000, 11]. It sets the radon concentration level to 500 Bq/m³ as annual average limit and to 3 mSv/y as effective dose for 2000 working hours/year.

2.3.1. Active radon detector Radim 5WP

Continuous radon gas concentration measurements were carried out by Radim 5 device (Jiri PlchM.Eng. SMM company, Prague). The radon concentration is determined by measuring the α-activity of its products, 218Po and 214Po, from diffused radon gas inside the detector chamber, by means of a silicon detector. The radon concentrations are recorded every half hour in non-volatile memory. The advantages of this instrumentation are its low cost, small dimensions (200x150x90 mm approx 0.5Kg), robust water-proof box with windows covered by radon permeable foil, processed data completely transferrable to a PC, powered by alcaline batteries, enough operating time (minimum 300 days), high sensitivity (0.3 count/h Bq/m³), limited humidity
dependence of response, large memory capacity (340 days of measurements corresponding to 16364 individual measurements).

The pictures of the whole mobile laboratory: Radim 5WP and Babuc are reported in figures 5-7.

The maps of the three catacombs with the measuring points are reported in figures 8-10.

3. Results

3.1. Interdisciplinary research

The most important result has been the perfect synergy between two disciplines so different from each other: physics and architecture. This means that the winning strategy in the research field should be the wide cooperation looking for the results in order to prove to what extent this theory is valid. The start of the interaction is always difficult to reach not only for different cultural backgrounds and inclinations, but also for the actual economical and bureaucratic restrictions. Moreover it is worth realizing a whole mobile laboratory which allows a real time monitoring of all environmental parameters which was only hypothetic till some years ago. Radim connected to a PC and Babuc monitor guarantee a daily real time monitoring of the radon concentrations as well as of the chemical and physical environmental parameters. If a wireless connection is possible, both the instruments allow a remote check, storage and data analysis without being obliged to spend more time in removing the...
instruments, in going into the laboratory and then in repeating the wrong measure. Moreover both instruments are very easy to manage, move and use. This implies high usability of all their capacities. They are totally worth using.

3.2 Economical and health workers consequences

Easy check of environmental conditions imply that many sites could be classified correctly notwithstanding their age construction. Monitoring environmental parameters allow to prevent the historical sites from developing decay which is the cause for the complete loss of a very important heritage: their memory.
and the witness of the places and their impact on the history and development of mankind. In this way many ancient places would become accessible and so, tourism could be upgraded in Campania region. There are so many amazing sites which have been abandoned only because it is impossible to prove their use and easy recovering or restoring. Our research proves that monitoring radon concentration, taking into account all the environmental parameters involved in it, is really important to settle the guides security. They have to be aware of the health risks they are exposed to and at the same time to be reassured as far as their health is concerned. The environmental parameters and pollutants monitoring is really important and represents a support tool in the identification of the evolution of degradation of the tuff and in the analysis of the state of conservation of the frescoes. The impact of pollutants, under certain conditions of temperature and humidity, is enormous and irreversible on the stone artefacts and decay processes are accelerated.

4 Conclusions and future actions
As far as the measurements are concerned, we are still working in progress. In addiction it will be possible to monitor the concentration of the particulate to estimate the daughters radon contribution on lung cancer risk. The real results is that the catacombs are not only amazing and worth preserving and visiting, but they are also a real wonderful natural laboratory, where the health impacts of contaminants are studied. The monitoring of radon and environmental parametric allows you to process dynamic maintenance plans where the timing of the inspection and that of the interventions can be constantly updated, improving the effectiveness and efficiency of maintenance activities [De Medici S., 2007, 751].

This idea of interdisciplinary interaction represents an innovative approach for simultaneous control on archeological sites not only to preserve historic manufact from decay and neglect, but also to protect workers’ health employed within.

Notes
1 The term catacomb means “at the cave=κατακυμβα=cata cubma” but it originally stood for the pozzolana quarries outside the walls of Rome. Since IX century “ad cata-cumbas” will then be used for all the early Christian cemeteries.
2 arcosolium: type of burial consisting of an arc, dome, or bezel, for decoration which could be a mosaic or fresco and below it the tomb to lay the body (one or more burials). The form symbolizes the sky because the soul goes to heaven.
3 cubiculum (Latin bedroom, the Christian rests awaiting the resurrection): private chapel could be closed by gate made of wood or metal, space instead were illuminated cross skylights and clay lamps placed on shelves along the walls.
4 This Byzantine family consisted of the child “Nonnosa” richly dressed with the crown, the prize for her virginity, died at 2 years and 10 months, the father Theoctenus, the mother Hilaritas wearing purple robes for the death of her loved ones.
5 In Christian iconography the peacock symbolizes the immortality of the soul which enjoys eternal life. In the past it symbolized the awakening of life in the spring because it loses and renews the feathers, while the “wheel” of his tail, became picture of a
starry sky. The image dated IV century depicts the bird in a garden full of flowers on a background of petals of roses, a sign of eternal happiness achieved by the dead buried in the tomb.

6 Highly distinctive element of the Dominicans is the burial of the dead skulls directly into the walls of the ambulacrum. The body was painted and accompanied by caption and historical elements indicating the social status of the dead.

7 It is the oldest environment of the upper level, a chapel built between the II and III century a.C., decorated with the most ancient Christian paintings of Southern Italy in Pompeian style, typical for the score of the ceilings and the use of colors (purple, yellow ocher, blue). In Fig. 5a there is Adam pointing out Eve after the Original Sin as Christian symbol.

8 Drains: seats gouged in the tuff with a vessel subjected, in which the dead were laid out to dry before being placed in a common ossuary or in a private tomb. To avoid dropping the head were dug holes for the skulls. This burial is typical of the Capuchins to overcome the problem of hygienic safety: the dead, once deposed, was no longer being exhumed.

References

Abstract
The theoretical considerations and operational experiences on the issues of protection and preservation of historic centers have led to the maturation of awareness to implement usability and enhancement circuits of the architectural heritage. In this scenario, an important theme is the rehabilitation of urban areas with cultural value, such as historical cemetery areas. This study analyzes the underground cemetery areas of cultural value in the historic center of Naples, in particular the Catacombs. Because of catacombs consist of basilicas dug in the tuff, ancient graves, niches and crypts enriched by many frescos and mosaics all around, has been settled down this mobile laboratory to evaluate the impact of CO₂ concentration and humidity on frescos and mosaics and the impact of the radon concentrations on the touristic guides’ health.

Procedures for the acquisition of environmental parameters are proposed to incorporate these spaces in a circuit of new fruibility.