# Gelati Monastery - Church of Virgin

KUTAISI - GEORGIA


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| Project |
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| A2320 |
| SCALE |
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| A2320_Piano_indagini.docx |
| Protocol n. |
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## PLAN FOR STRUCTURAL INVESTIGATIONS AND MONITORING

| Rev. | Date | Description | Prepared | Verified | Approved |
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| 3 | | | | | |
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| 1 | 12/07/2023 | 1ª ISSUE | Amici/Niccolai | C. Russo | -- |

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# 1. INTRODUCTION

This document illustrates the structural investigation campaign that will be conducted on the masonry of the "Church of the Nativity of the Virgin," which is the main church within the Gelati Monastery complex in Kutaisi, Georgia. It also includes technical characteristics and location of instruments related to static monitoring system. The purpose of this monitoring system is to effectively control and track the evolution of the crack pattern over time.

# 2. EXPLORATORY INVESTIGATIONS

In the following chapters, we introduce and define analyses that aim to deepen our understanding of the structure's current knowledge and obtain useful parameters for a subsequent evaluation of the seismic behavior.

In particular, from the first analysis focused on evaluating the state of conservation of the monument, the need has emerged to investigate certain aspects concerning the existing wall structures. The proposed investigations which involve both on-site tests and laboratory analyses on samples taken from the site, aim to examine the composition of the materials comprising the masonry structures, specifically the stone elements and bedding mortars. The objective is to characterize these materials in terms of their type and state of conservation. The investigations also aim to examine the geometry of the wall structure's components and their state of conservation.

## 2.1. PREVIOUS INVESTIGATIONS

Previous investigations, as well as the findings from prior studies and observations, were taken into account when selecting the type, quantity, and location of tests.

In particular, to acquire knowledge about the mineralogical-petrographic characteristics of mortars and stones, the results from previous studies and investigations already conducted in the past and made available to the Client were reviewed and analyzed.

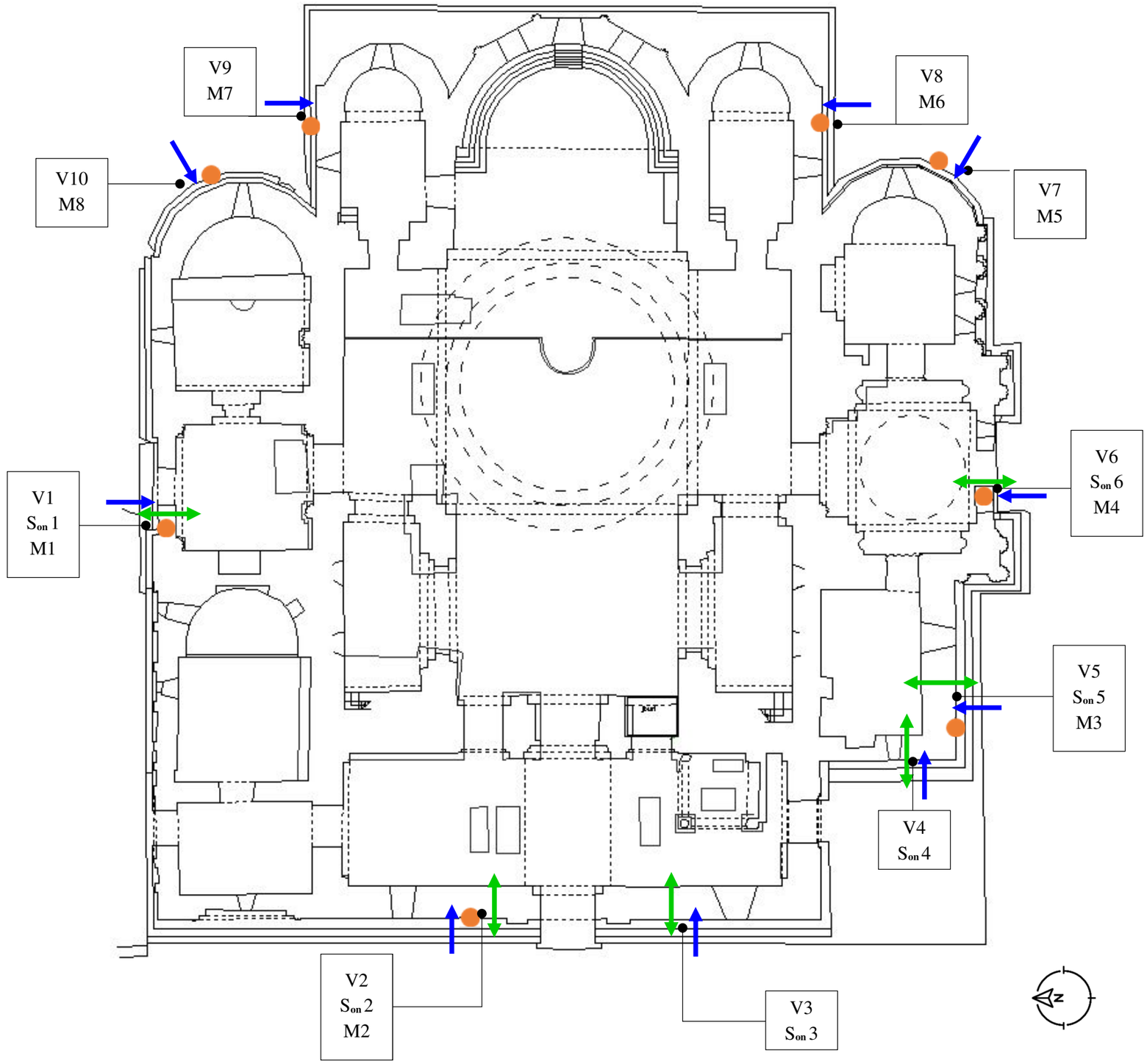
## 2.2. SUMMARY OF EXPLORATORY INVESTIGATIONS

The diagnostic study aims to enhance the level of understanding of the structure through on-site instrumental investigations aimed at identifying the type of materials and the geometry of the elements composing the masonry. It also involves a series of laboratory tests to determine the nature of the materials constituting the masonry.
The summarized list of number and type of tests that need to be conducted is as follows:

| TESTS ON MASONRY ELEMENTS | |
|---|---|
| **10** | **VIDEOENDOSCOPIC INVESTIGATION** |
| **6** | **SONIC TESTS** |
| **8** | **MORTAR SAMPLING**<br><br>**for subsequent laboratory testing:**<br>• **MINERALOGICAL-PETROGRAPHIC ANALYSIS**<br>• **THIN SECTIONS OF MORTAR**<br>• **X-RAY DIFFRACTION ANALYSIS (XRD)**<br>• **GRANULOMETRIC ANALYSIS** |

The following chapter shows the floor plans with the preliminary locations of the listed investigations.
The exact location will be agreed with the responsible person in charge of the monument in order to minimize the aesthetic impact while still obtaining the necessary information.

## 3. INVESTIGATIONS LOCATIONS




| LEGEND | | |
|---|---|---|
| TESTS ON THE MASONRY ELEMENTS | | |
| ● | M…: | MORTAR SAMPLING |
| ↔ | Son…: | MICROSEISMIC – SONIC INVESTIGATIONS ON MASONRY |
| ← | V…: | VIDEOENDOSCOPIC INVESTIGATIONS |

# 4. TESTS ON THE MASONRY ELEMENTS – INVESTIGATIONS DESCRIPTION

## 4.1. VIDEOENDOSCOPIC INVESTIGATIONS

### 4.1.1. *Method description*

Videoendoscopic investigation consists of a slightly invasive technique primarily applied to determine the condition and type of masonry structures.

### 4.1.2. *Preliminary operations*

The inspections are carried out within drill holes with a diameter of 20 mm, performed using a rotary hammer drill (core destruction), after cleaning the hole.

### 4.1.3. *Test execution:*

The investigations are carried out using a rigid or flexible probe equipped with a camera and axial lighting.
The videoscope is connected to a digital recording system, which allows the storage of video inspections of each drill hole.

### 4.1.4. *Results*

For each inspected hole, a schematic graphic representation illustrating the stratigraphic sequence of the masonry layers encountered, some photo frames extracted from the video footage, and an attached digital copy of the entire recording will be provided.

## 4.2. MORTAR AND AGGREGATE SAMPLES

The investigations include laboratory analysis of significant samples of masonry taken on-site, where indicated, in order to characterize them from a chemical and physical perspective. The sampling should be carried out where indicated (in areas already characterized by fractures and damages) or in any case where it does not cause additional harm or aesthetic disturbance to the existing structures.

## 4.3. LABORATORY ANALYSIS TO BE PERFORMED ON THE SAMPLES OF MORTAR AND AGGREGATES

The characterization obtained from the laboratory analysis of the samples extracted on-site is crucial for understanding the critical aspects of the individual materials and, therefore, for determining the level of intervention and selecting the most appropriate technique to ensure the best result.

The following tests will be conducted on each extracted sample:

### 4.3.1. *MINERALOGICAL-PETROGRAPHIC ANALYSIS WITH THIN SECTIONS*

### 4.3.2. *GRANULOMETRIC ANALYSIS OF MORTAR SAMPLES*

### 4.3.3. *X-RAY DIFFRACTION ANALYSIS (XRD)*

## 4.4. MICROSEISMIC – SONIC INVESTIGATIONS ON MASONRY

### 4.4.1. *Method description*

The microseismic-sonic investigation on masonry aims to assess the level of compactness of the examined masonry, identify the presence of voids within it, and evaluate the condition of the mortar and constituent elements.

Sonic investigations are carried out using the so-called "transparency" technique, which consists of placing a transmitter and receiver on opposite faces of the same wall in order to determine the value of the longitudinal wave propagation velocity through the thickness of the wall. By measuring the velocities, it is possible to make comparative assessments of the degradation state and homogeneity of the masonry. Due to the high levels of dispersion encountered during this type of testing, it is generally not possible to establish analytical relationships with the elastic moduli and strength of the material itself.

By calculating the percentage ratio between the standard deviation (σ) and the average velocity (Vm), an index is established to evaluate the uniformity of the velocity throughout the structural element. Comparing this index to a reference value (7 * 10%), which takes into account measurement errors and typical variations encountered in masonry, provides an accurate assessment of the uniformity of the investigated area. In general, it can be stated that high values of σ/Vm indicate the possible presence of cracks/cavities and are typically indicative of heterogeneous masonry.

For the execution of sonic investigations, real-time sampling instrumentation is used, allowing the waveform to be displayed on a laptop computer monitor and enabling the simultaneous acquisition of signals from the sensors.

#### 4.4.2. *Test execution*

Each measurement is performed by placing the piezoelectric transmitter on one part of the structural element to be investigated and the receiver on the opposite side. Given the distance "d" between the receiver and transmitter, the velocity of the sonic wave through the walls is derived as the ratio "d/t".

#### 4.4.3. *Results*

The data is presented both in tabular and graphical form. In particular, the graphical representation uses a color-coded visualization of the recorded velocity values at the grid nodes, which allows a quick visual assessment of any mechanical characteristic non-uniformities within the structural element.

# 5. AUTOMATIC STATIC MONITORING SYSTEM

## 5.1. **INSTRUMENTATION**

The proposed instrumentation will be wireless and capable of transmitting all acquired data in real-time through a gateway to a cloud server directly to the end user. web interface developed for the specific project will allow real-time visualization of the data and graphs acquired by the monitoring system. Additionally, it will be possible to set up alarms by sending push notifications or emails when predefined alarm thresholds are exceeded. The instrumentation will be fully battery-powered (with a possible solar panel) and will not require any maintenance from the Client. It will consist of:

**n. 2 displacement transducers** to be placed across the main fractures. This not only allows the assessment of any ongoing evolutionary phenomena, but also enables the determination of the amplitude of the oscillation. Consequently, it becomes possible to assess the actual forces that need to be counteracted, if considering the insertion of reinforcement chains or implementing effective repair interventions of the fractures.

**n. 4 wire displacement transducers** to be placed on top of the previously consolidated longitudinal cracks of the South (top) and North (bottom) wall

**n. 5 ambient temperature sensors** to be placed inside and outside the church, which will serve as the basis for interpreting any evolutionary processes not directly correlated to seasonal thermal cycles.

n**. 4 ambient humidity sensors** which measure the water vapor content of air.

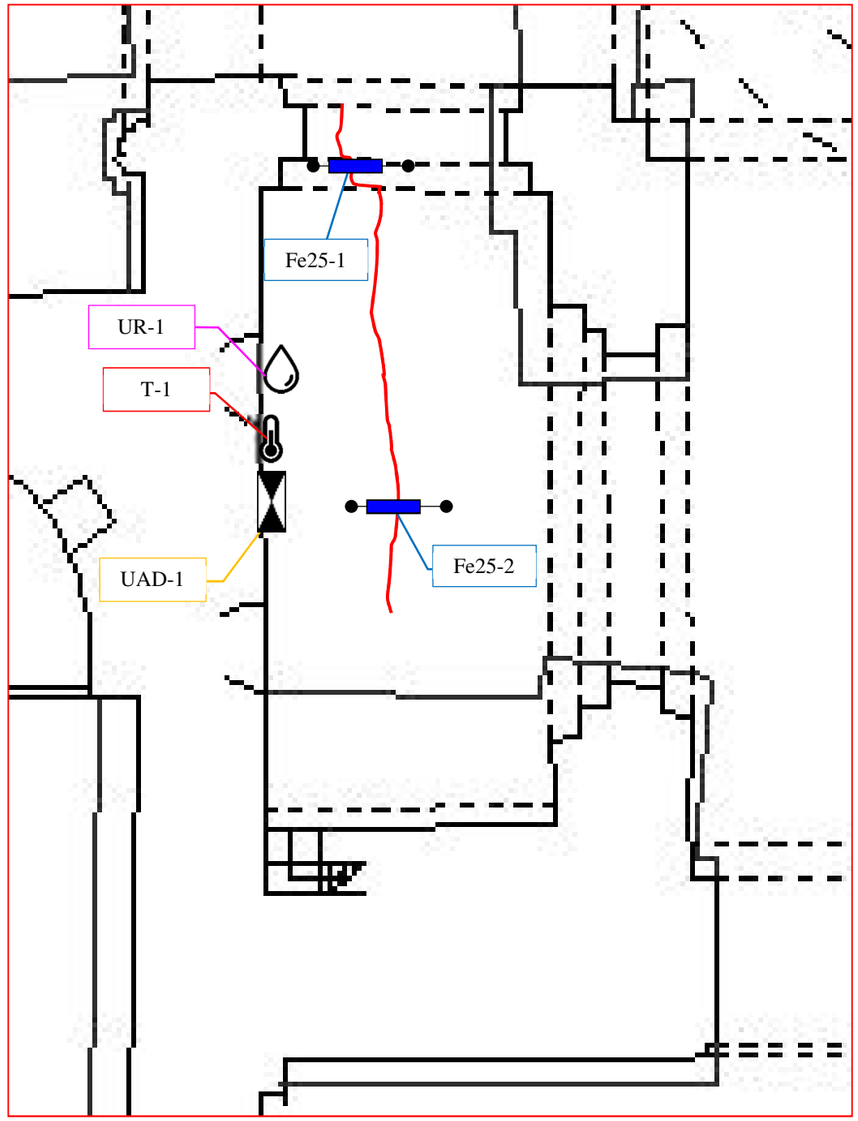
The system will be completed with n. 3 datalogger and gateway for data transmission to the cloud server.

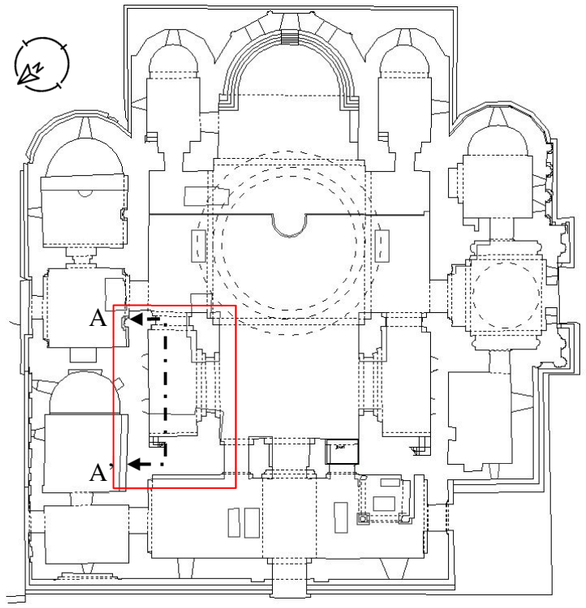
The data will be subsequently processed, interpreted, and provided in a report that will be transmitted to the Client every six months.

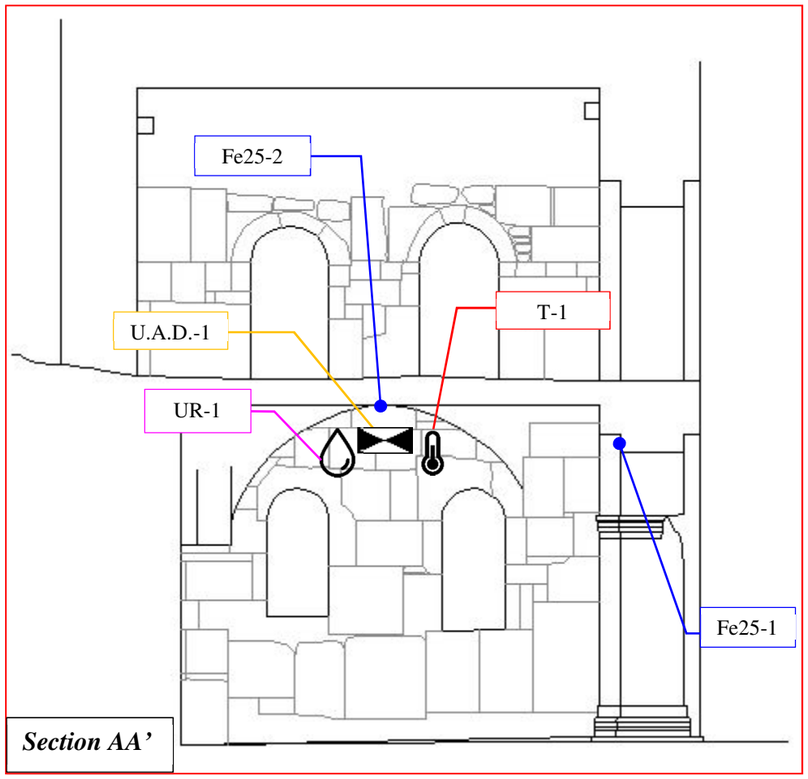
The system will allow to fix in advance and change - should the evolution of the phenomenon require it - the acquisition interval at which the unit queries the connected instrumentation (from a few seconds to a few hours), in order to effectively have a continuous description of the evolution of the monitored variables.

Below is a photographic documentation of the site and the indicative location of the foreseen sensors.

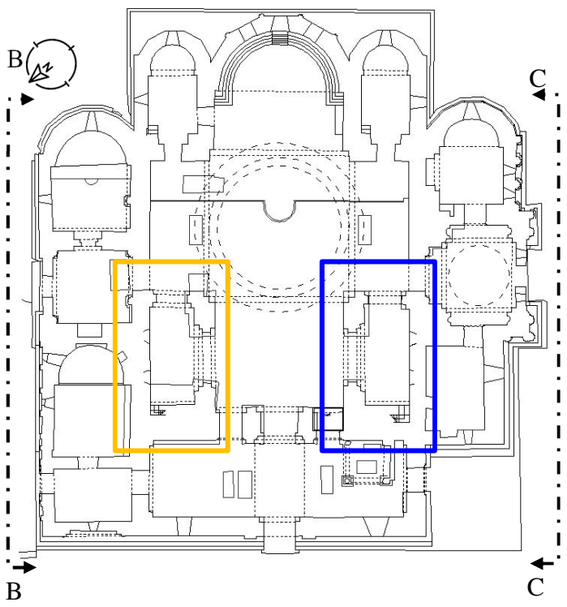
## 5.2. MONITORING LOCATIONS

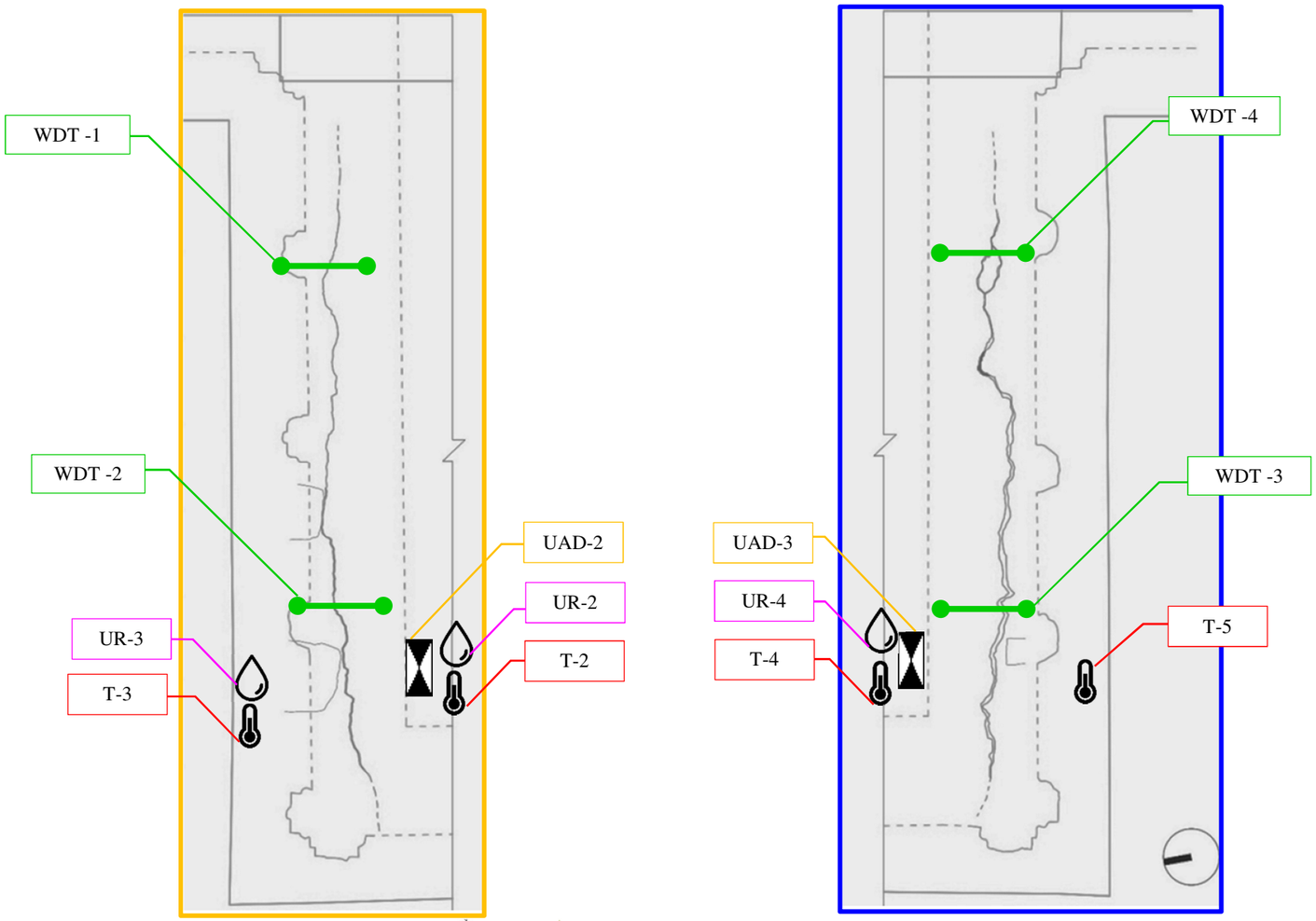


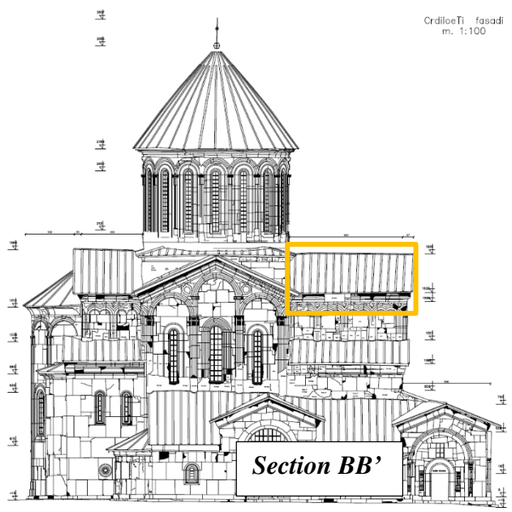



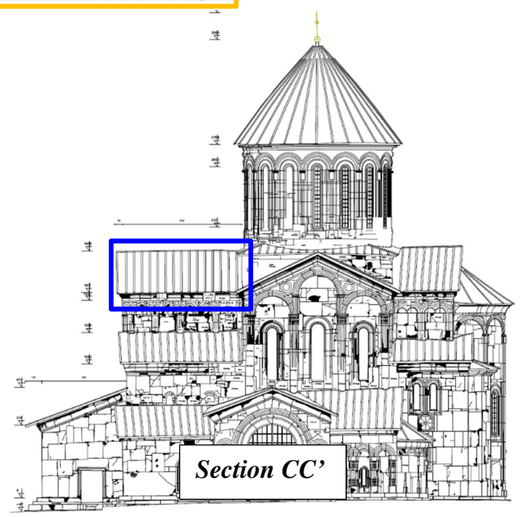




| | | |
|---|---|---|
| | F25-…: | Displacement transducers |
| | WDT-… | Wire displacement transducer |
| | T-…: | Ambient temperature sensors |
| | U.A.D.-… | Data acquisition unit |
| | UR-… | Relative environmental humidity |



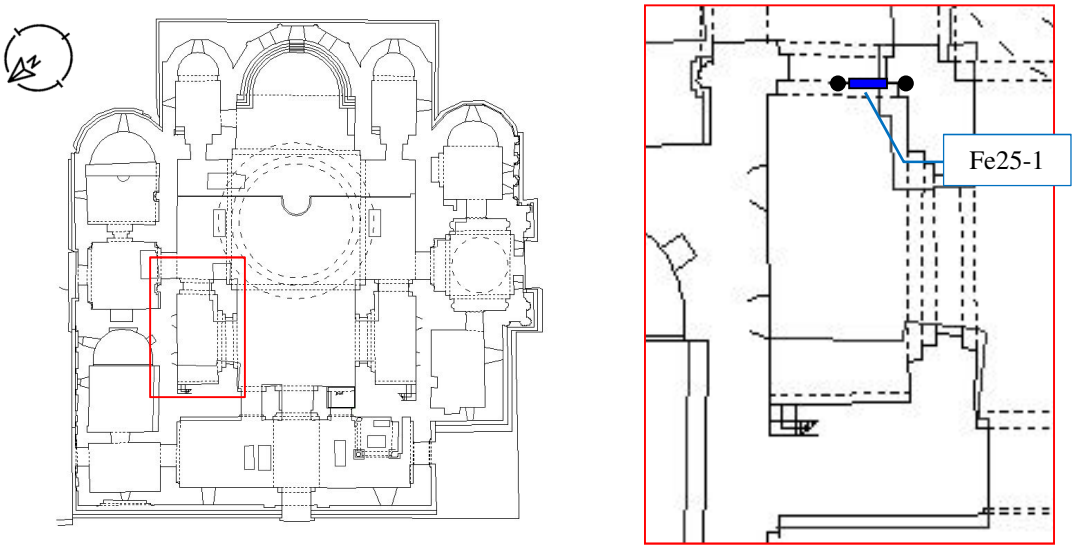



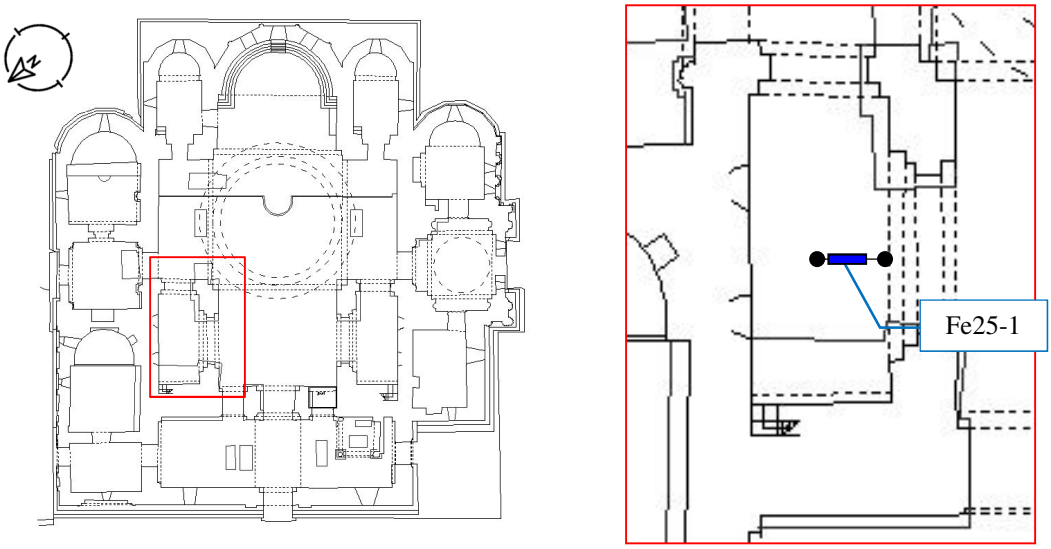

| | | |
|---|---|---|
| | F25-…: | Displacement transducers |
| | WDT-… | Wire displacement transducer |
| | T-…: | Ambient temperature sensors |
| | U.A.D.-… | Data acquisition unit |
| | UR-… | Relative environmental humidity |

### 5.2.1. *FOTOGRAPHIC DOCUMENTATION*



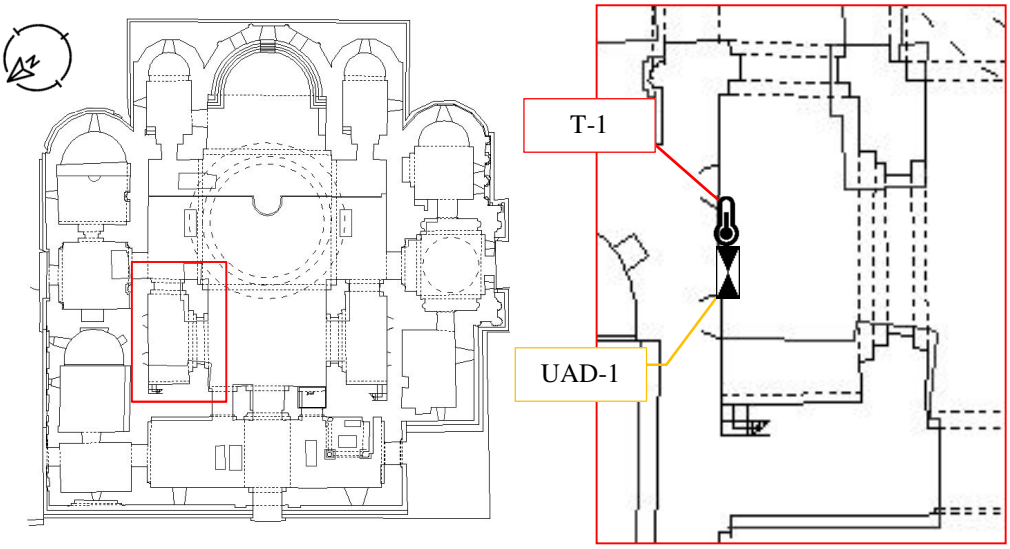


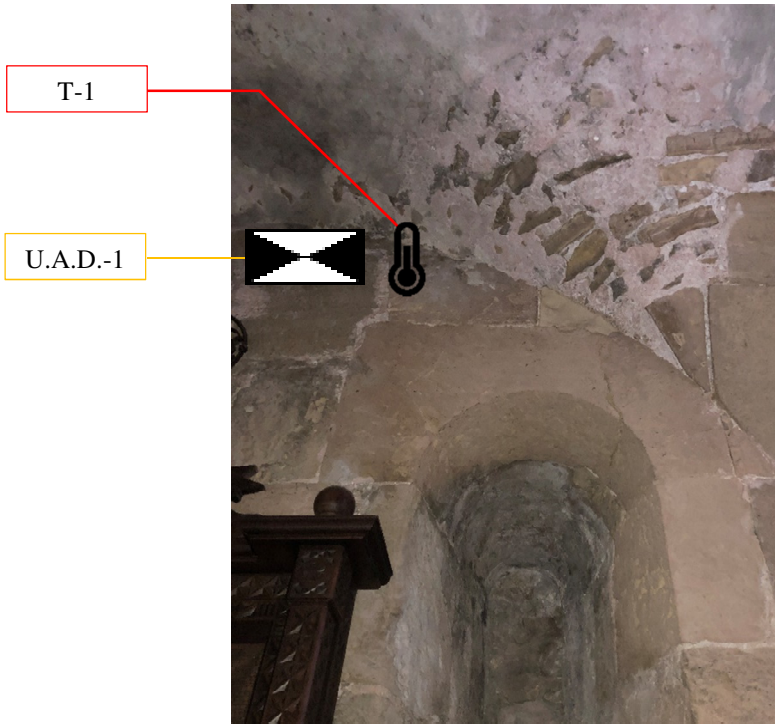
*Displacement transducers Fe25-1*





*Displacement transducers Fe25-2*




*Data Acquisition Unit UAD-1 and environmental thermometer T-1*

- **Charges at our expenses**

- Consumable materials;
- Preparation of technical reports in paper format (2 copies) and electronic format (1 copy).

- **Charges at your expenses**

- Assembly and disassembly of scaffolding to reach the height points;
- Accessibility of the test areas;
- Supply of electricity 220 V (1KW) at each test point;
- Technical drawings to be used for the location of investigations;
- Site access authorizations;
- Removal of any fixed or mobile obstacles that could impede carrying out the tests;
- Restoration of the holes made for carrying out video endoscopic investigations;
- SIM for internet connection or LAN cable near the gateway;
- Everything that is not expressly indicated in the “charges at our expenses”;

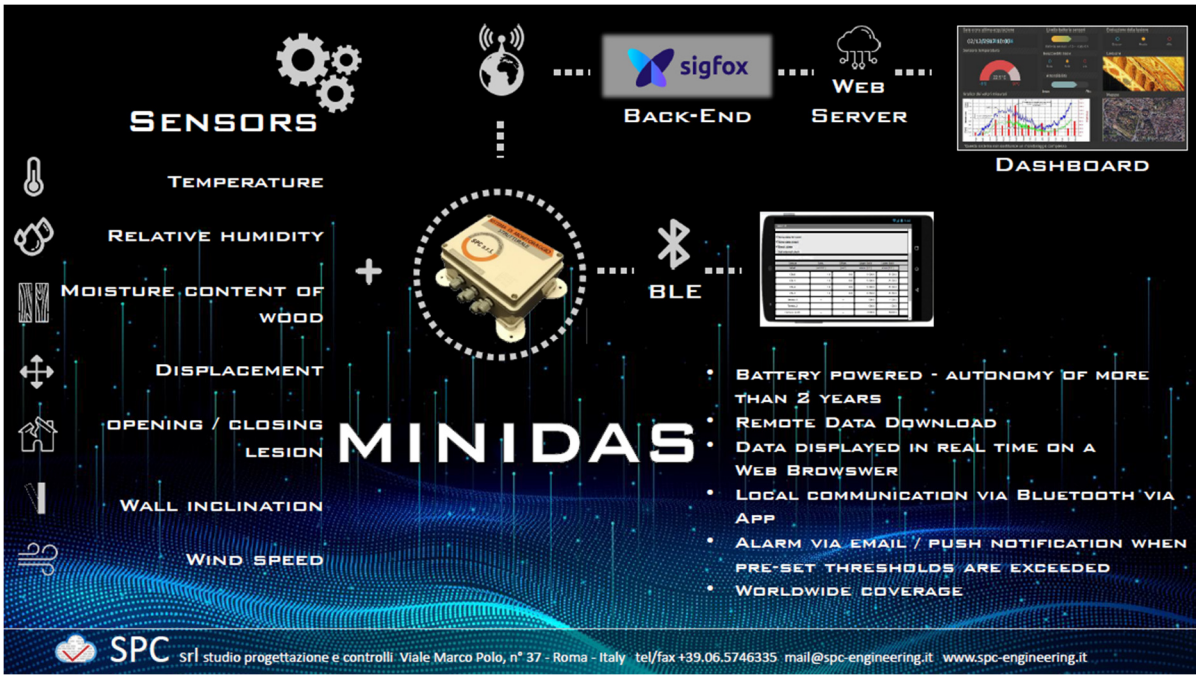
I look forward to your kind response.

Best regards
SPC S.r.l.
Eng. Cristiano Russo

# 7. ANNEX“A” – MONITORING SYSTEM TECHNICAL CHARACTERISTICS

## 7.1. DATA ACQUISITION SYSTEM

the datalogger is a fully programmable standalone data acquisition and control unit with non-volatile memory and a battery backed clock in a small, rugged, sealed module. It is housed in a waterproof enclosure with a power supply. The data acquisition system reads the output of a range of sensors and then digitizes, processes and stores the results, according to the given programming. Data can be retrieved to a PC locally or over a remote communication link.
The installed device is a versatile datalogger suitable for a wide range of applications in science, industry and research. Typical applications are: environmental monitoring and control, structural monitoring, industrial testing, automatic weather stations and agricultural research.
The data acquisition system has switched outputs to power bridge-type sensors such as PRTs, strain gauges, load cells, pressure transducers and thermistors. The instruction set allows to control measures (analogue voltage, impulses), data processing (mathematical functions such as square root and polynomials up to fifth grade), data storage (max, min, average, standard deviation, total, etc.) and programming (programs can include conditional executions, loops and subroutines).
The data acquisition system operates from - 20 °C to + 70 °C, the inputs are fully protected against lightings and electric transient, so it can work in different environmental conditions. The channels are 8 differential, with a 4 digit resolution and ±0.1 % accuracy.



## DATA ACQUISITION SYSTEM - TECHNICAL FEATURES

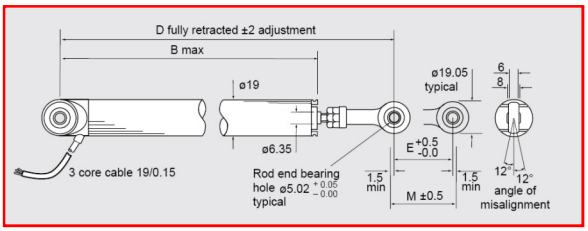
| | |
|---|---|
| Available channels | 4 analogici + 2 sensori di temperature digitali |
| Memory type | RAM con batteria al litio in tampone |
| Measurement type | Voltage (max 5V) |
| Saving capability | 150.000 acq con SD da 16 Gb |
| Conversion | 16 bit (reali) |
| Data format | Compatibile EXCEL (ASCII) |
| Precision | 0.1% |
| Protection | IP66 |
| Dimensions | 265x130x75 (scatola standard) |
| Stability | 100 ppm |
| Sampling rate | From 1 sec (zero heating time) to 24h |
| Energy absorption | 45 mA (+1 del canale in misura), 5 µA in stand by |
| Tempo di periscaldamento sensori | Da 0.1 a 25.4 sec |
| Power supply voltage | 5÷12 V dc |
| Communication | Bluetooth |
| Internal battery supply | 7.4 V con batterie Li-ion ricaricabili e pannello solare o batterie Lisoci non ricaricabili |
| Operating temperature | -20/+60°C |

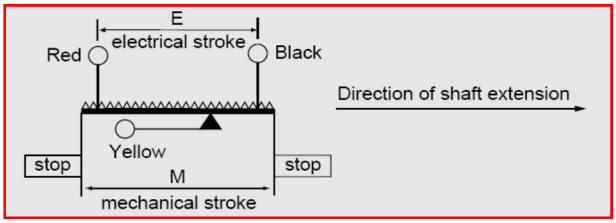
## 7.2. DISPLACEMENT TRANSDUCER

The displacement sensors have been designed to obtain maximum performance while maintaining an extremely compact size.
The applied technology is the "Hybrid Track technology" which consists of a high resistivity conductive plastic film wound on a precision coil.
The conductive plastic film then flows across a high precision metal contact. This technology guarantees practically infinite resolution and high durability. The temperature coefficient is extremely low, while the resistance remains practically stable as the humidity varies.
The sensor is equipped with ball joints at the end which allow precise positioning and direct movement always along the axis of the instrument. Finally, the instrument is protected by an aluminum container which gives it an IP66 degree of protection.

**TECHNICAL FEATURES**

| | |
|---|---|
| Electric stroke | 25 mm |
| Resistance ±10% | 1 KΩ |
| Independent linearity | Granted 0.25%<br>Typical 0.15% |
| Dissipation at 20°C | 0.5 W |
| Maximum applicable voltage | 22 Vcc |
| Electric output | Min. 0.5% - Max 99.5% of applied tension |
| Resolution | Practically infinite |
| Repeatability | Minor of 0.01 mm |
| Operating temperature | -30 ÷ 100 °C |
| Isolation | > 100 MΩ a 500 V cc |
| **Dimensions** | |
| Electrical stroke E | 25 mm |
| Mechanical stroke M | 29 mm |
| Body length | 110.5 mm |
| Centres distance D | 173.6 mm |
| Approx weight | 109 g |
| Electrical connexion | 3 wires with PVC sheath |



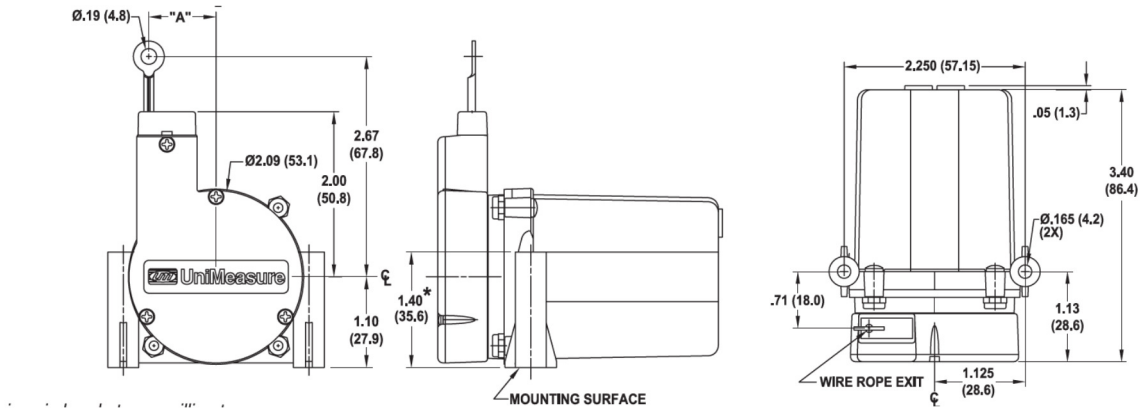
## 7.3. **WDT - WIRE DISPLACEMENT TRANSDUCER**

This type of sensor allows to measure the relative displacement of two points connected by an inextensible wire in stainless steel. The instrument is equipped with a return spring that keeps the cable always at the right tension.

The chemical resistant thermoplastic case of the transducer provides protection for applications where exposure to wash down, rain, oil and other liquids may occur. The sealed case is achieved through the use of o-rings and a low friction shaft seal. An integral dust wiper insures that the wire rope stays clear of debris as it is extracted and retracted.

**TECNICAL FEATURES**

| | |
|---|---|
| Measurement Range | 2" (50 mm) |
| Sensing Device | Precision Potentiometer |
| Resolution | Essentially Infinite |
| Linearity | +-1.0% Full Scale |
| Repeatability | 0.02% Full Scale |
| Construction | Thermoplastic Body |
| Wire Rope | Φ 018 (0.46 mm) Jacketed Stainless Steel |
| Wire Rope Tension | 4.4 N |
| Weight | 180 gm |
| Connections | Electrical cable, or plastic connector |
| Operating Temperature | -25°C to +75°C |
| Storage Temperature | - 50°C to +80°C |
| Operating Humidity | 100% R.H. |



## 7.4. AMBIENT TEMPERATURE SENSORS

The temperature sensor is of the digital type with an end encapsulated in stainless steel, which makes it perfectly watertight and submersible.

**TECHNICAL FEATURES**

| | |
|---|---|
| Measuring range | -55° ÷ +125°C |
| Resolution | 9 ÷ 12 bit |
| Precision | ± 0.5 °C |
| Linearity | ± 0.5 °C |
| Supply | 2.7 ÷ 5.5 V |
| Absorption | 0.5 µA |

## 7.5. SENSORS FOR MEASURING THE RELATIVE ENVIRONMENTAL HUMIDITY

The humidity sensor is a capacitive type of sensor, composed of laser-cut thermosetting polymers, and is complete with a signal conditioning circuit such as to make the analog output linear as the humidity content in the air varies.
The multilayered construction of the sensing element provides excellent resistance to most application hazards such as condensation, dust, dirt, oils and chemicals common in measurement environments.
The accuracy of the measurement, considered between 11% and 89% relative humidity, is +/- 1%, while the response time to humidity variations is approximately 5 seconds.

## 7.6. MODEM ULTRA-NARROWBAND

The device used for this specific application is a modem that uses a so-called ultra-narrow band at 868 MHz which allows the transmission of a sufficient amount of data to manage a monitoring system with extremely low energy consumption.

**TECHNICAL FEATURES**

| | |
|---|---|
| Web type | Ultra narrow band |
| Band | 868 MHz |
| Range of action in urban areas | 15 – 20 Km |
| Daily messages in uplink | 140 msg |
| Supply | Internal batteries 2600 mAh + Solar panel 10W |
| Measuring range | -10°C ÷ +55°C |

## 7.7. MULTIPOLAR SHIELDED CABLES

For the transmission of the signals from the instruments to the datalogger are used four and six-conductor cables, with sections 0.22 □ 0.5 mm2. They have a shield made of red copper, with a covering more than 85%, to prevent electric interferences and a protection to external agents, they are also non-inflammable according to CEI 20-22 standards.