Gelati Monastery - Church of Virgin

KUTAISI - GEORGIA

Studio Croci & Associati & VI Studio

A. Bozzetti, F. Croci, A. Herzalla, C. Russo – V.Zesashvili

Roma - Viale Marco Polo, n° 37
Tel/Fax +39 06.5746335
mail@studiocroci.it

Project
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A4, A3
FILE
A2320_R_03_Periodic_report.docx
Protocol n.
A 2 3 2 0 / R / 0 3

Responsible for the order:
Eng. Alessandro Bozzetti
Eng. Cristiano Russo

Collaborators:
Eng. Azzurra Amici
Geom. Matteo Niccolai

STRUCTURAL MONITORING SYSTEM

Activities Periodic Report

Rev.	Date	Description	Prepared	Verifed	Approved
3					
2					--
1	03/09/2024	1ª ISSUE	Amici/Niccolai	C. Russo	--

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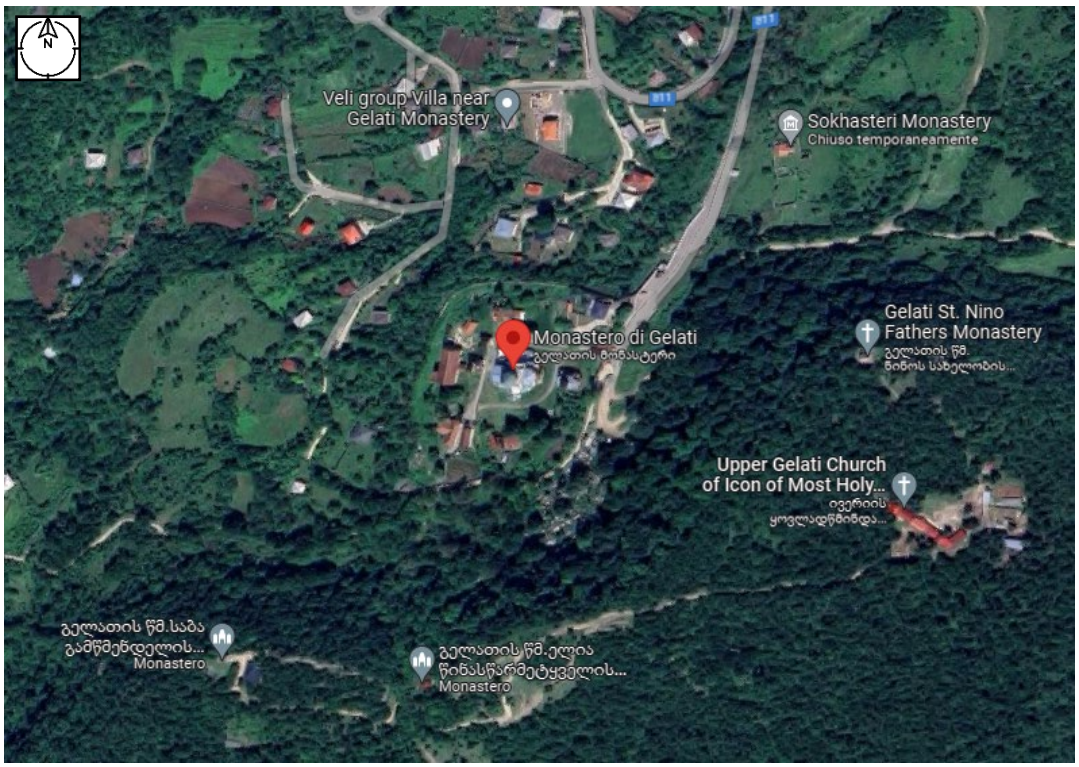
1. INTRODUCTION

This report concerns the monitoring system of the Church of the Nativity of the Virgin, in the monastic complex of Gelati, in Kutaisi - Georgia.
Details about system technical features and sensors locations are exposed.



The monitoring system, whose installation has been carried out from November 2 to November 3 2023, consists in:

- n° 2 Displacement transducers;
- n° 4 Wire Displacement Transducers;
- n° 6 Temperature sensors;
- n° 3 Data Acquisition System;
- Gateway ultra narrow band for data transfer;
- software for data visualization and storage on a web server platform.

Starting from 3 November 2023, the system acquires physical data from the instruments every 4 hours (6 daily acquisitions). The data acquisition system stores data in an internal memory and send the data in an internet accessible cloud server with any browser.

For each sensor a proper alarm threshold is set and the system automatically informs the user with an alert email every time the limit is reached.
A remote check of the correct functioning of the entire system is periodically carried out.
The data are finally processed and diagrammed using specific programs.

2. MONITORING SYSTEM TECHNICAL CHARACTERISTICS

2.1. DAS - DATA ACQUISITION SYSTEM

The data logger is an independent acquisition device suitable for the creation of remote unattended data collection stations.

The remote station carries out the measurements autonomously according to the given programming and it records the data in its memory (SD card) until it is transferred to the user system. At the same time it writes the acquired data into a file archived via a cloud storage service.

The data it's elaborated and plotted in real time on a world wide web page reachable from any device with internet connection.

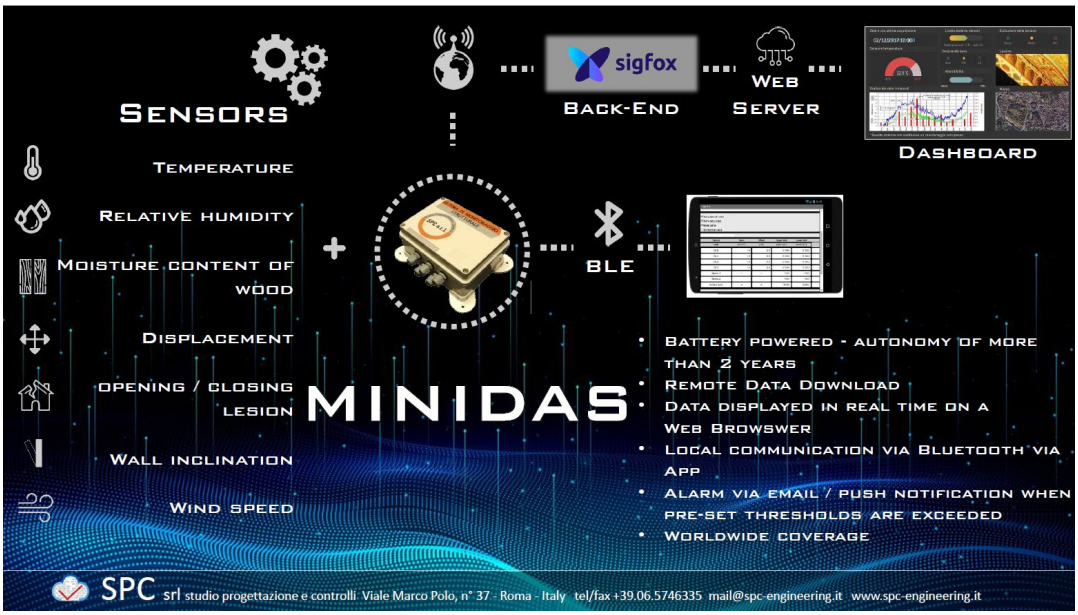
The data acquisition system was developed to allow great flexibility on the different types of measurement possible.

The versatility of input configuration allows the connection of sensors with different analog signal characteristics and number of conductors.

Programming performed via smartphone with Bluetooth connection allows you to define the measurement configuration for each type of sensor.

For each sensors a proper alarm threshold is set and the system automatically informs the user with an alert email every time the limit is reached.

The software also allows you to switch from electrical units (V, A, Ohm) to physical units (temperatures, forces, deformations, rotations, etc.)



A technical sheet with the main characteristics of the data acquisition system are illustrated below.

DATA ACQUISITION SYSTEM - TECHNICAL FEATURES

Available channels	4+2 (possible configurations 2-4-8)
Memory type	RAM with buffer lithium battery
Measurement type	Voltage (max ±5 V)
Capacity	5117 readings on 1 channel; readings on 4 channels; 2274 readings on 6 channels)
Conversion	16 bit
Data format	Compatible EXCEL (ASCII)
Precision	0.1%
Protection	IP66
Dimensions	265x130x75 (standard box)
Stability	100 ppm
Sampling rate	From 1 sec (zero heating time) to 24h
Energy absorption	45 mA (+1 of the measured channel), 10 μA in stand by
Sensor preheating time	from 0.1 to 25.4 sec
Power supply voltage	5÷12 V dc
Communication ports	Mircro USB
Internal battery supply	12 Vcc – 6 A/h with 8 alkaline batteries LR14 size C
Operating temperature	-20/+60°C
Serial communication RS232	8 bit, No parity, 1 stop bit, 9600 baud

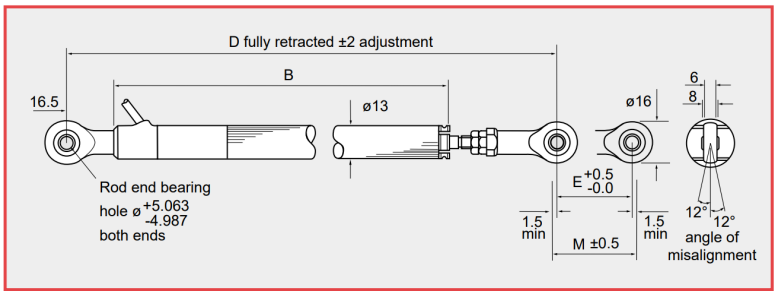
2.2. DISPLACEMENT TRANSDUCERS

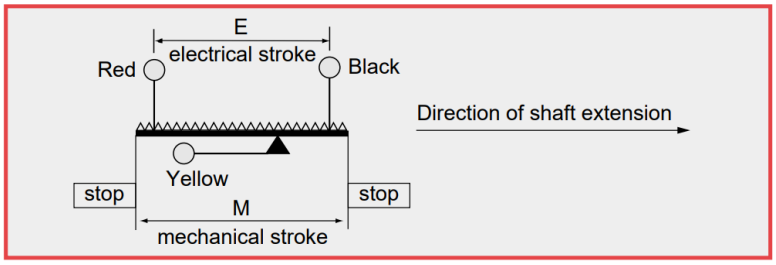
Displacement transducers used have been designed to obtain the maximum performances with a extremely compact dimensions. “Hybrid Track” technology is applied: it consists in a conductive plastic film with high resistivity rolled up on a high precision coil. Conductive plastic film slides trough a high precision metallic contact. This technology grants an infinite resolution and a high durability. Temperature coefficient is extremely low, while the resistance remains practically stable at humidity variations.
Sensor is provided with spherical joints at the end that allow a precise positioning and a movement always directed along the axis of the instrument. At least, the sensor is protected form an aluminium container that confers the protection grade IP66.

A technical sheet with the main characteristics of the displacement transducers are illustrated below.

TECHNICAL CHARACTERISTICS (CEN –004-029)

Performance	
Electric stroke	25 mm
Resistance ±10%	1 KΩ
Independent linearity	Granted 0.25% 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 °C ÷ + 100 °C
Isolation	> 100 MΩ at 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


D fully retracted ±2 adjustment
B
16.5
ø13
ø16
6
8
Rod end bearing
hole ø +5.063 -4.987
both ends
E +0.5 -0.0
1.5 min
M ±0.5
1.5 min
12°
12°
angle of misalignment


E
electrical stroke
Red
Black
Direction of shaft extension
Yellow
stop
stop
M
mechanical stroke

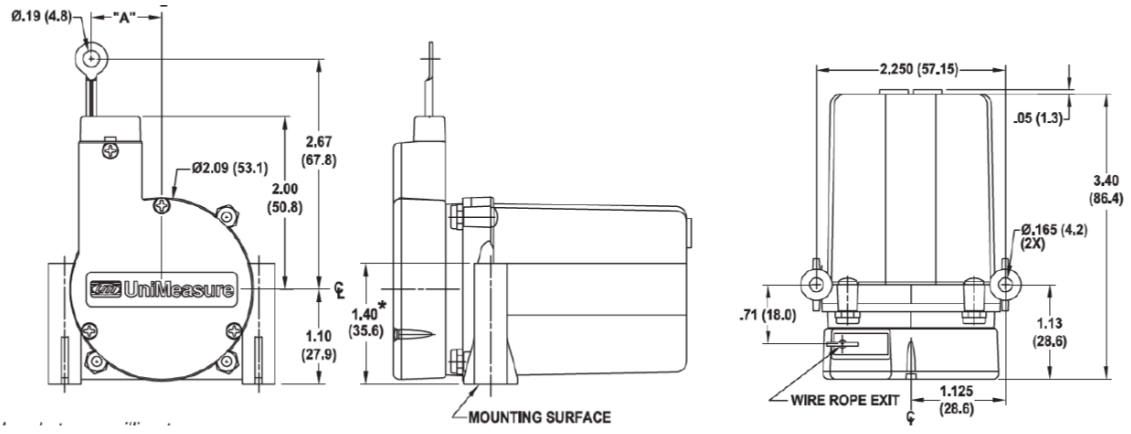
2.3. WDT - WIRE DISPLACEMENT TRANSDUCER

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.



2.4. ENVIROMENTAL TEMPERATURE SENSORS

The temperature sensor is digital with an encapsulated stainless steel end which makes it perfectly watertight and submersible.

TECNICAL FEATURES

Performance	
Operating range	-55° ÷ +125°C
Resolution	9 ÷ 12 bit
Precision	± 0.5 °C
Linearity	± 0.5 °C
Power supply voltage	2.7 ÷ 5.5 V
Energy absorption	0.5 µA

2.5. ENVIROMENTAL HUMIDITY SENSORS

The hygrometric sensor is of the capacitive type, composed of laser-cut thermosetting polymers.

It is equipped with a signal conditioning circuit that makes the analogue output linear while the humidity content in the air varies.

The multi-layer construction of the sensing element provides excellent resistance to most application hazards such as condensation, dust, dirt, oils and common chemicals found in measurement environments.

The accuracy of the measurement, considered between 11% and 89% of relative humidity, is +/-1%, while the response time to humidity variations is approximately 5 seconds.

2.6. GATEWAY ULTRA NARROWBAND

The device used for this specific application is a gateway 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.

TECNICAL FEATURES

Network type	Ultra-narrow band hopping
Band	868 MHz
Range of action in urban areas	15 – 20 Km
Daily uplink messages	140 msg
Power supply voltage	Alimentazione interna
Operating Temperature	-10°C ÷ +55°C

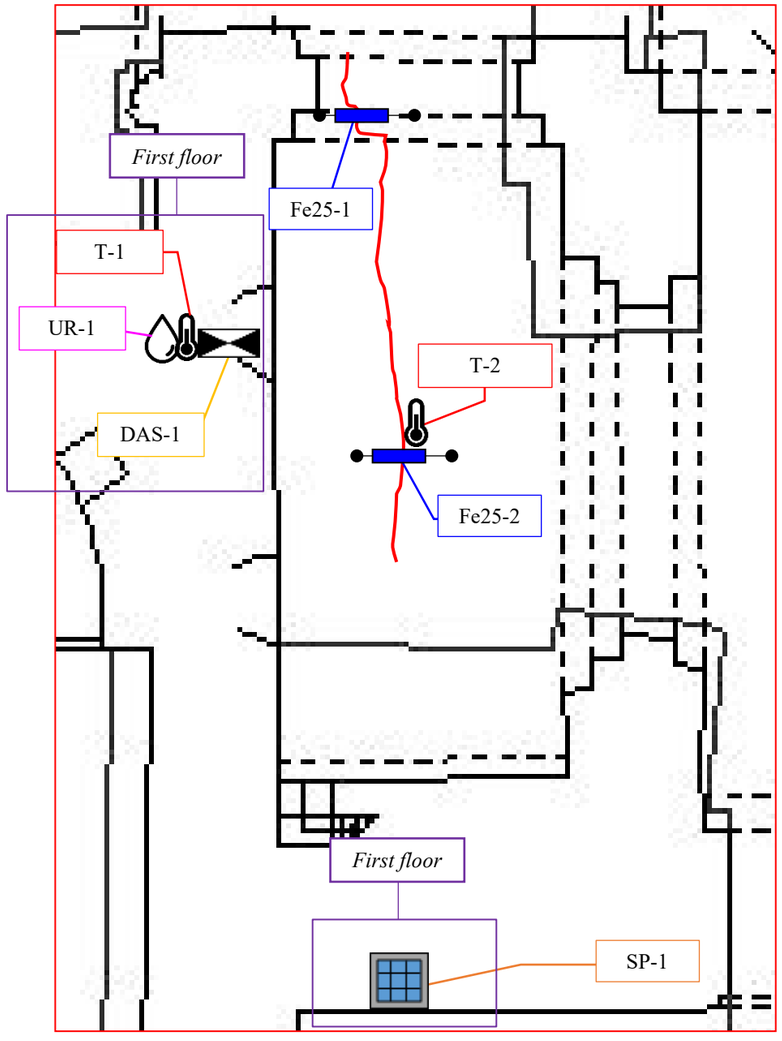
2.7. MULTIPOLAR SHIELDED CABLES

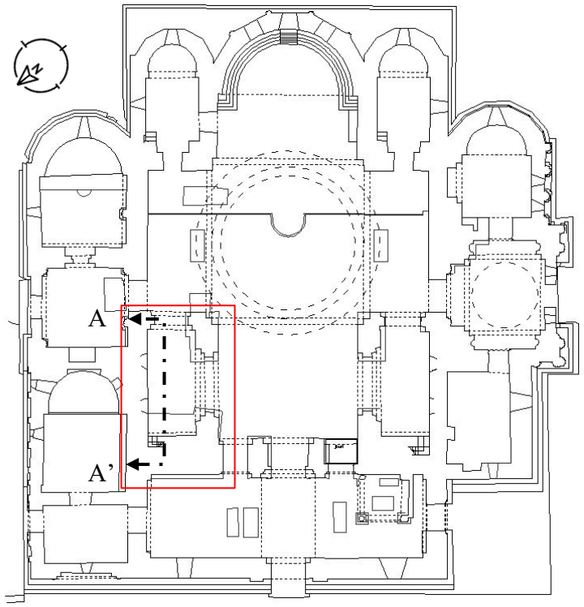
For the transmission of the signals from the instruments to the peripheral unit of acquisition are used four and six-conductor cables, with sections 0.22 ÷ 0.5 mm^2. They have a shield made of red copper, with a covering more than 85%, to prevent electric interferences and a protection to external agents, they are also non-inflammable according to CEI 20-22 standards.

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

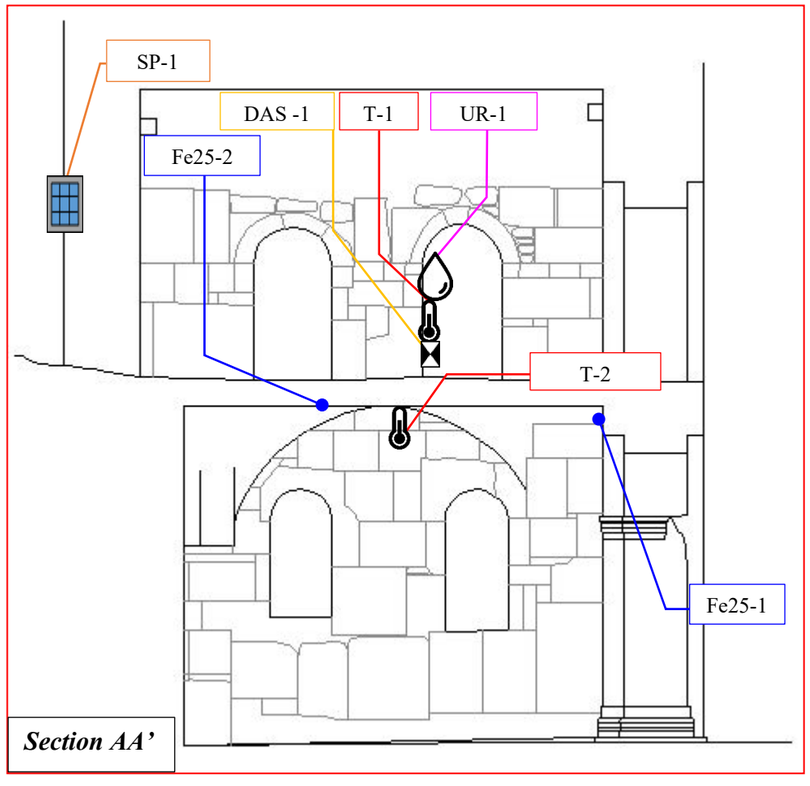
3. LOCATION OF THE INSTRUMENTATION AND PHOTOGRAPHIC DOCUMENTATION

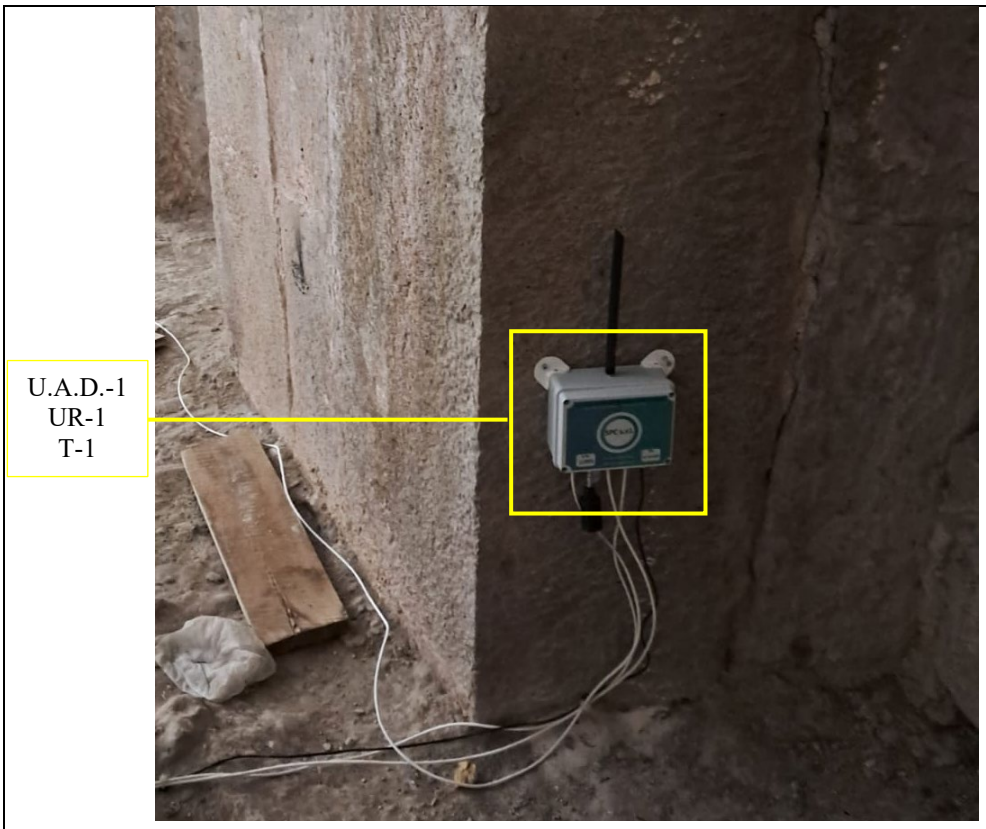
3.1. LOCATION 1



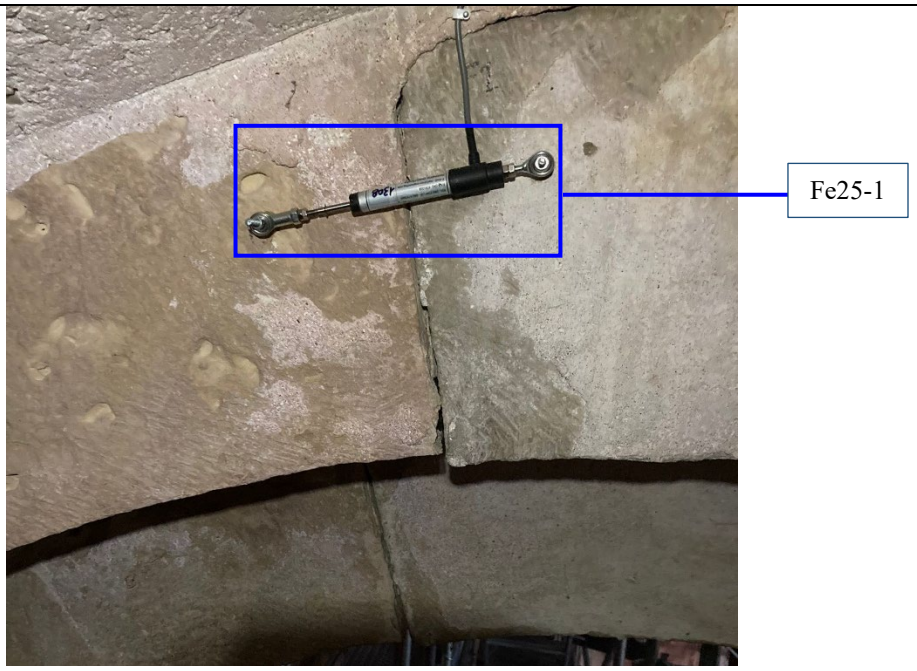


	Fe25-…:	Displacement transducers
	WDT-…	Wire displacement transducer
	T-…:	Enviromental temperature sensors
	DAS-…	Data acquisition unit
	UR-…	Relative environmental humidity
	SP-…	Solar Panel

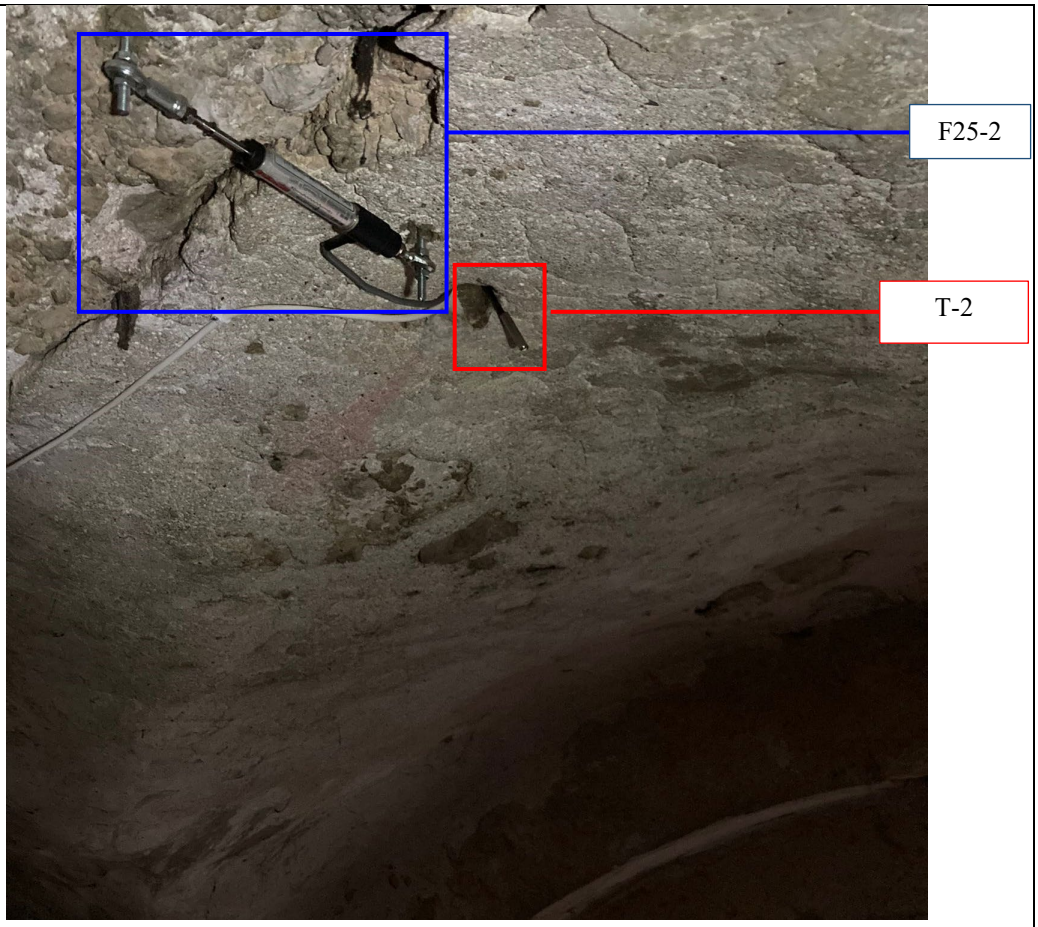




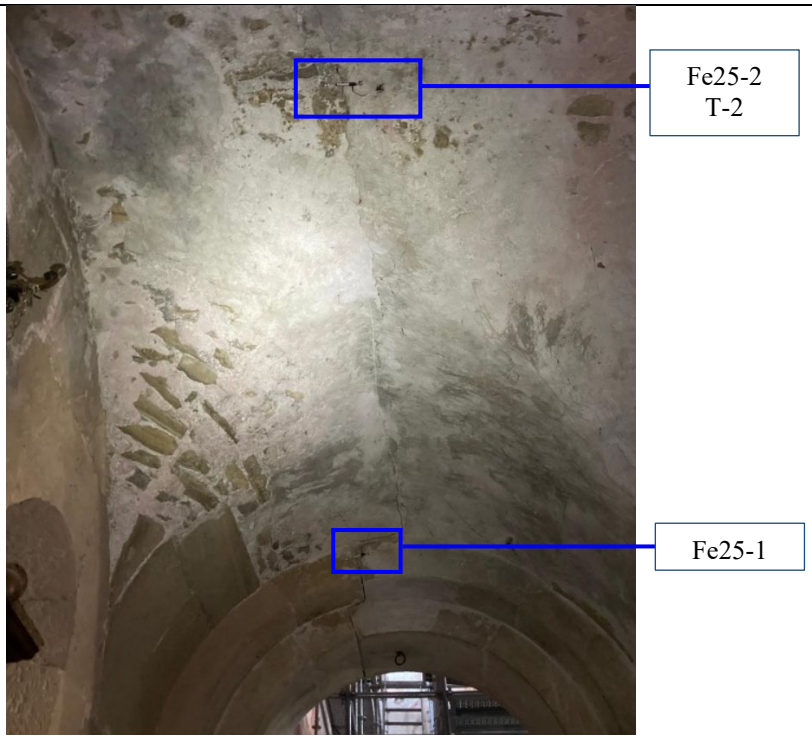
Data Acquisition System - DAS-1, Relative environmental humidity UR-1, Enviromental temperature sensors T-1.



Displacement transducer Fe25-1.



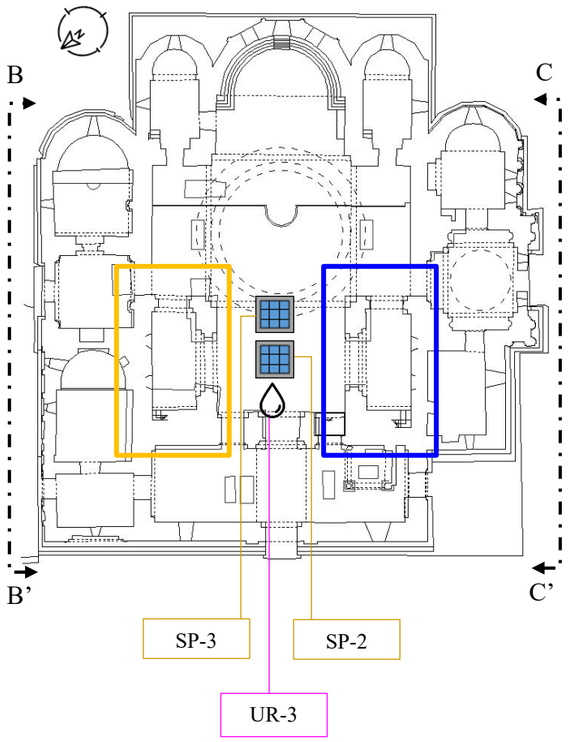
Displacement transducer Fe25-2, Temperature sensors T-2



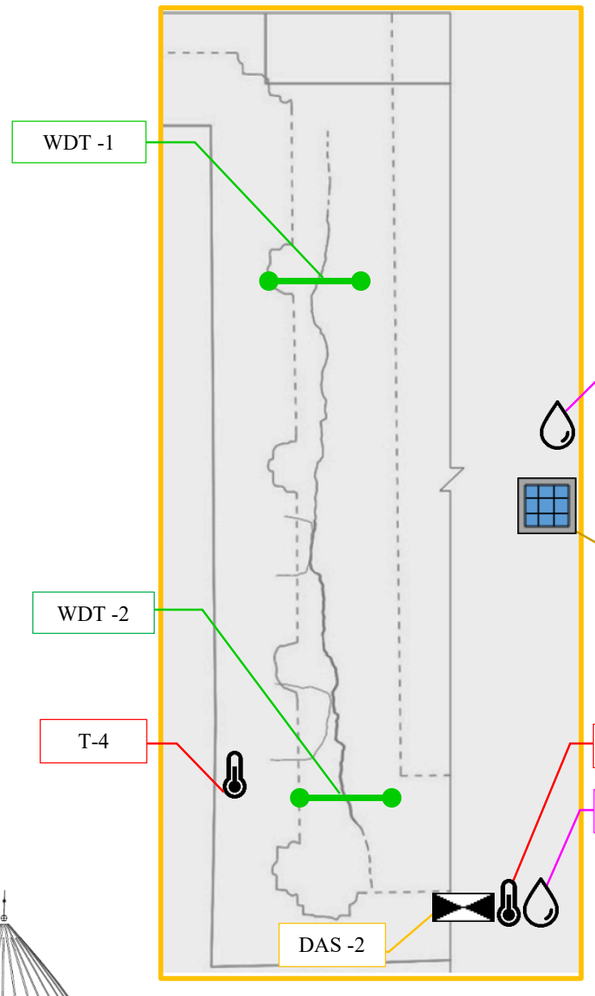
Displacement transducers Fe25-1 e Fe25-2, Temperature sensors T-2 wall.

Solar panel SP-1, Gateway Ultra Narrowband.

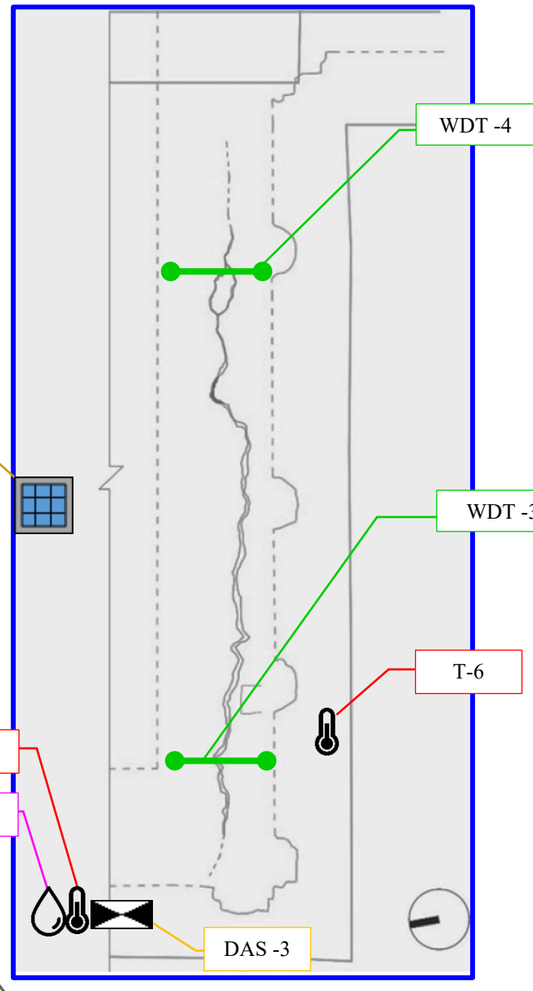
3.2. LOCATION 2 AND 3

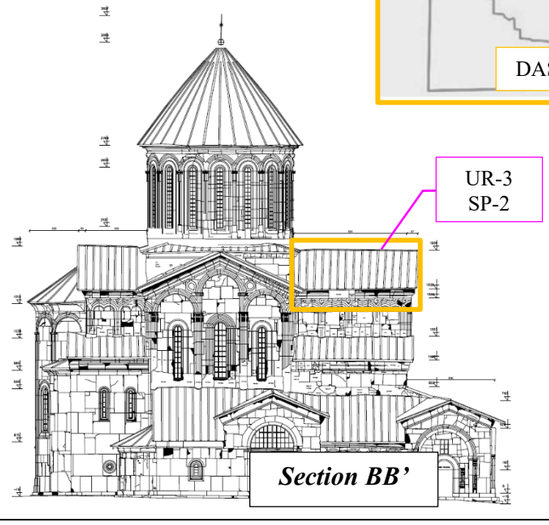


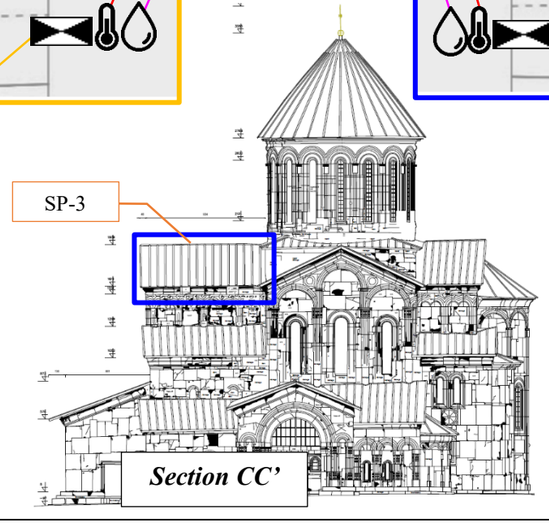
Location 2



Location 3







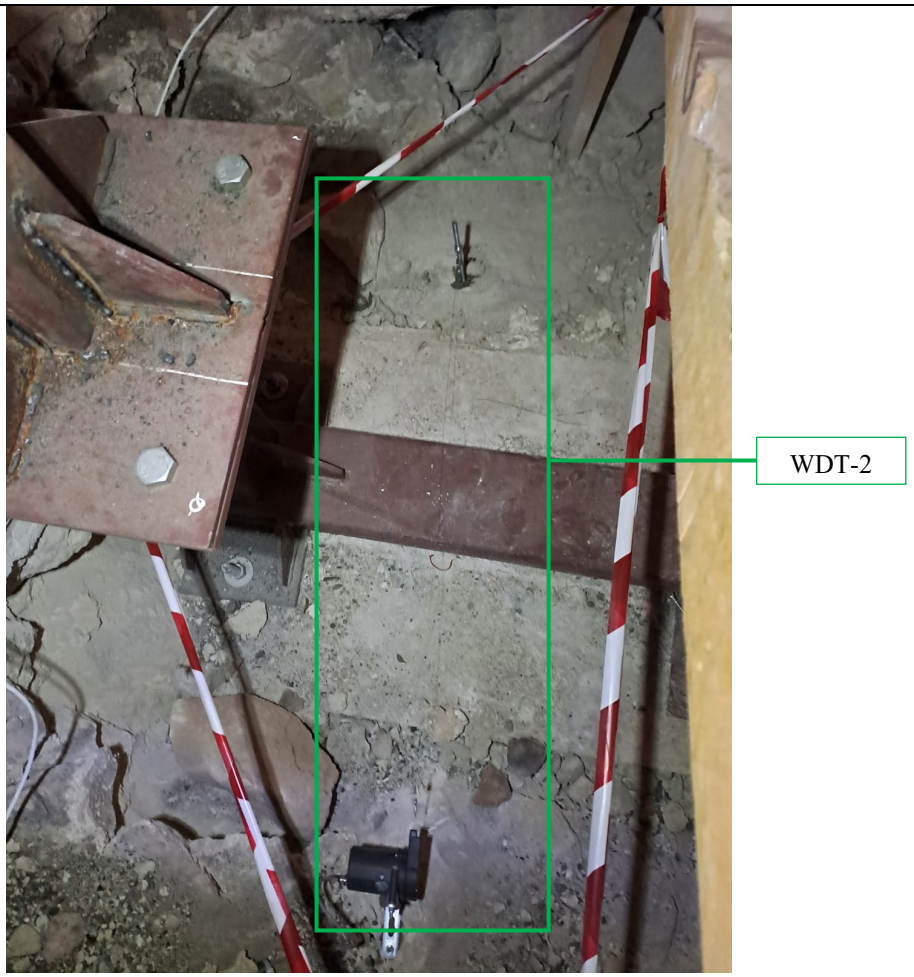
	Fe25-…:	Displacement transducers
	WDT-…	Wire displacement transducer
	T-…:	Ambient temperature sensors
	DAS -…	Data acquisition unit
	UR-…	Relative environmental humidity
	SP-…	Solar Panel

3.2.1. *Location 2*

Data Acquisition System - DAS-2, Relative environmental humidity UR-2, Temperature sensor T-3.

Temperature sensor T-4.

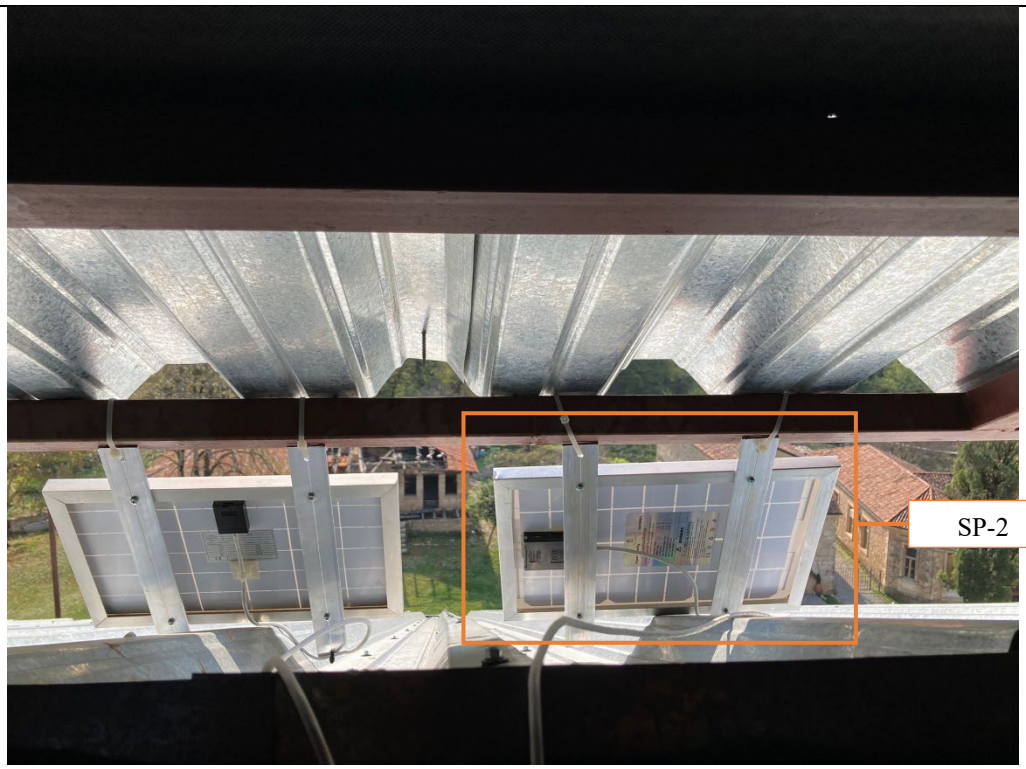
Wire displacement transducer WDT-1.



Wire displacement transducer WDT-2.

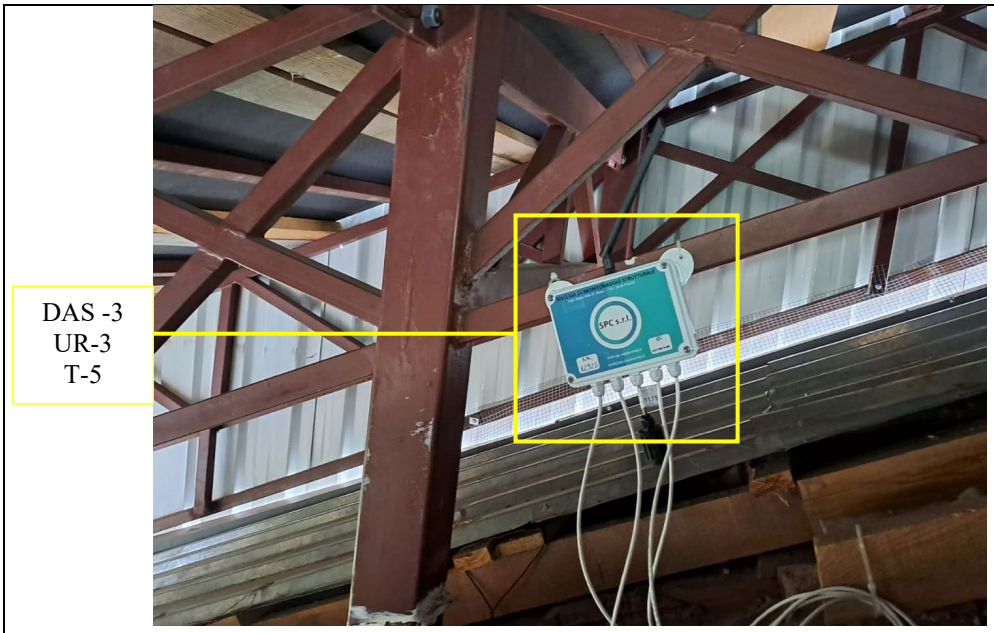
Wire displacement transducers WDT-1 e WDT-2

Relative environmental humidityUR-3.

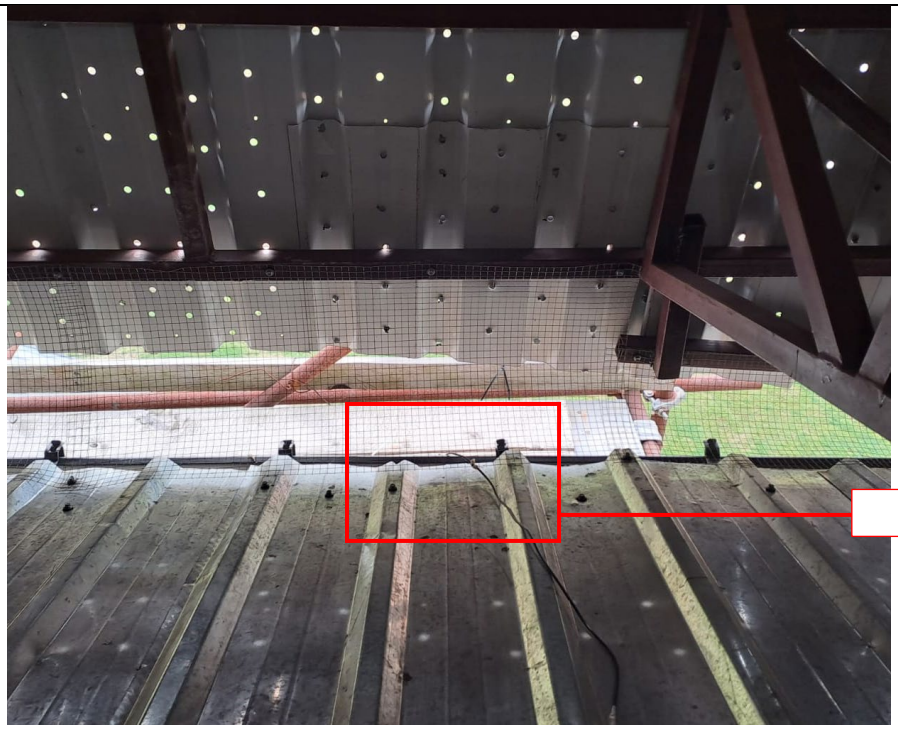


Solar panel SP-2.

3.2.2. *Location 3*



Data Acquisition System – DAS-3, Relative environmental humidityUR-4, Temperature sensors T-5.

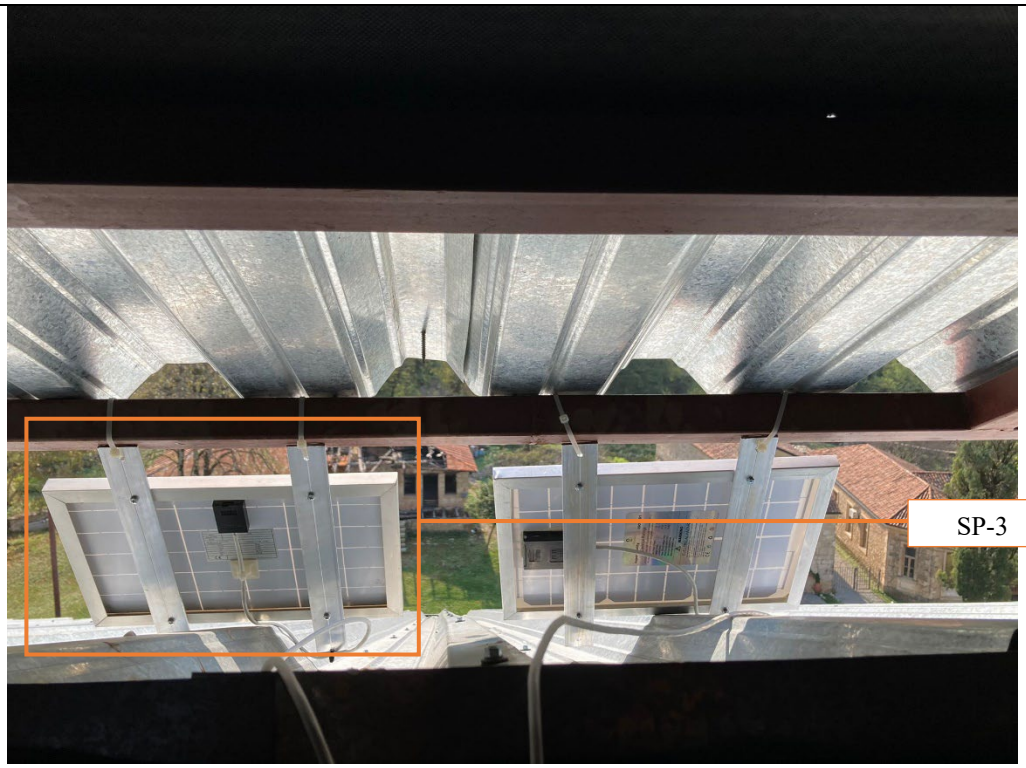


Temperature sensorsT-6.

Wire displacement transducerWDT-3.

Wire displacement transducerWDT-4.

Wire displacement transducerWDT-3 e WDT-4.



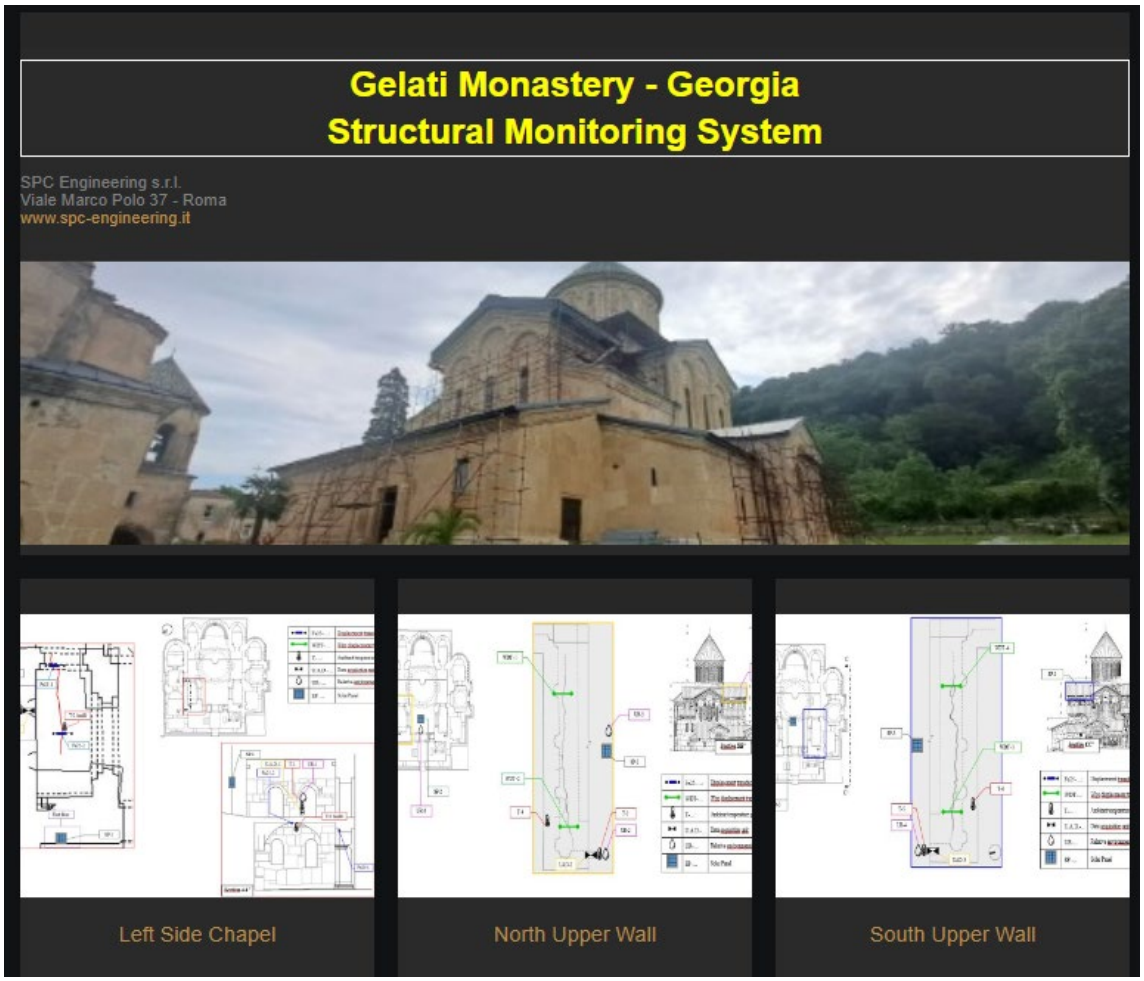
Solar panel SP-3.

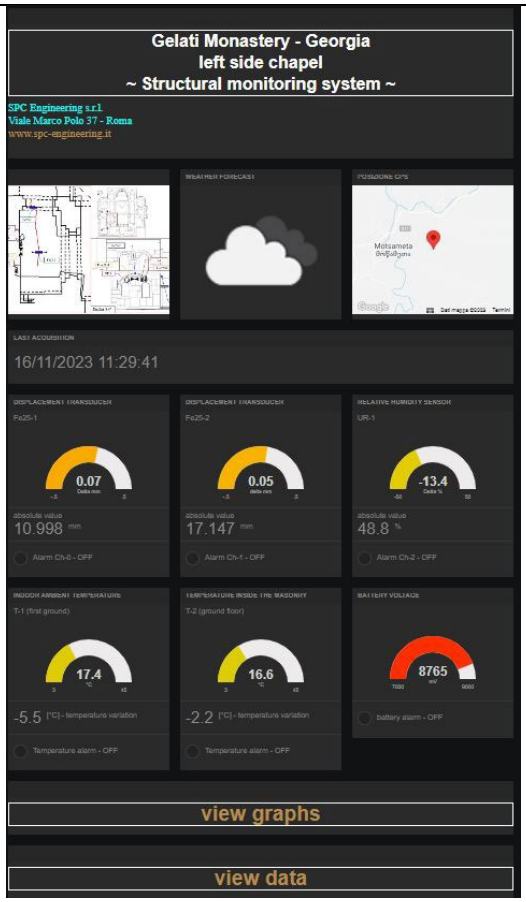
4. DATA DISPLAY PANEL

The data acquired by the dataloggers are saved on the cloud accessible via ftp and are elaborated and plotted in real time on a world wide web page reachable from any device with internet connection at the following link

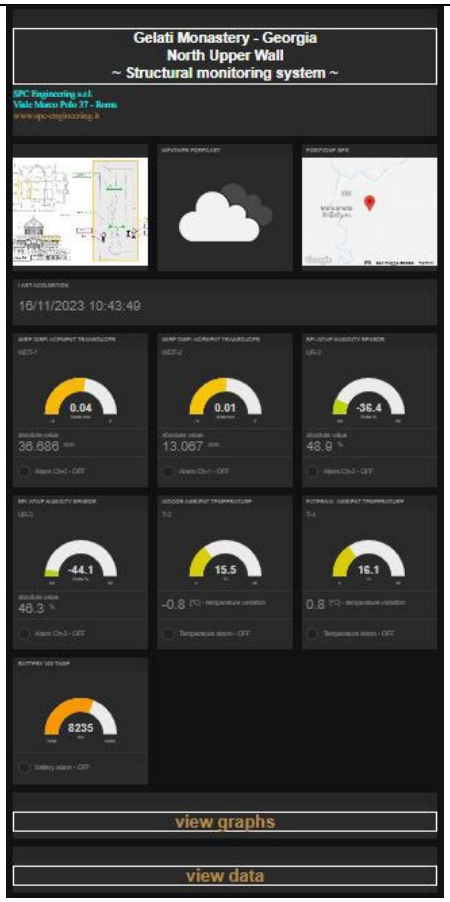
http://www.lesiometro.com/Gelati/

Below is a screenshot of the dashboard.

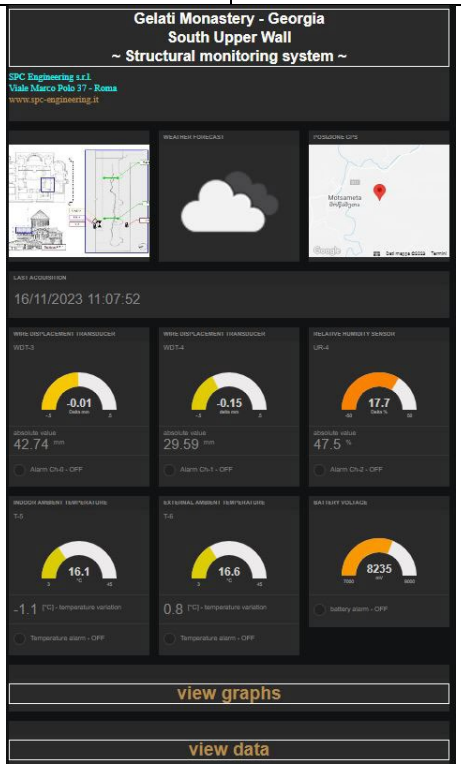




Dashboard location 1

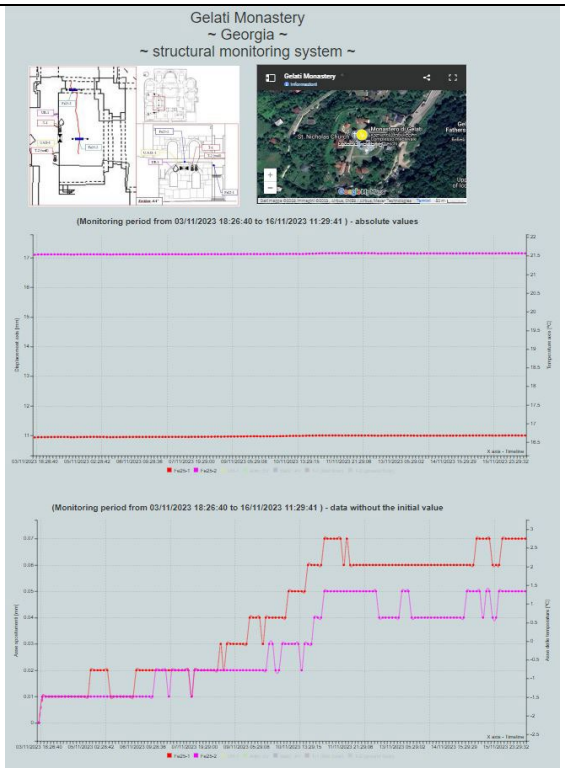


Dashboard location 2

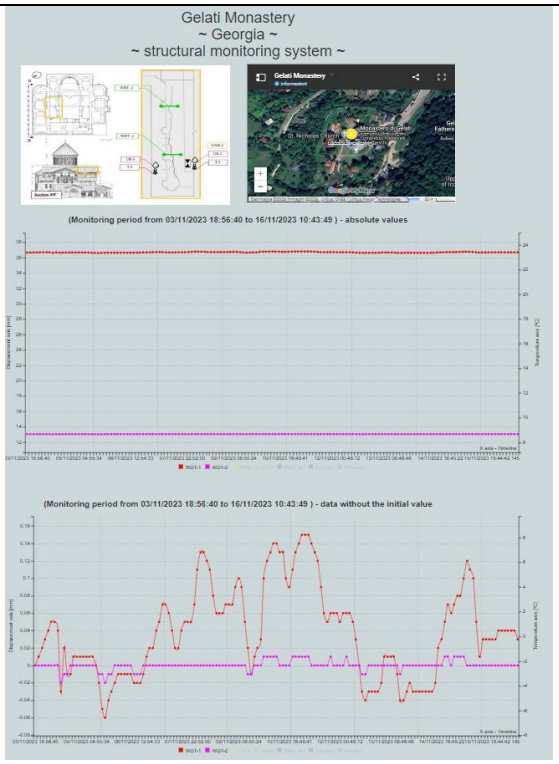


Dashboard location 3

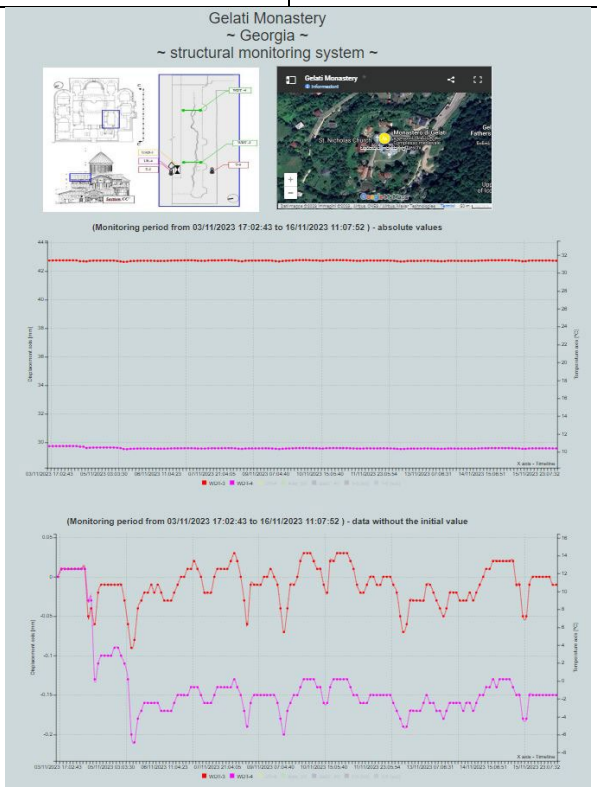
From the main screen it is possible to access the graphs and raw monitoring data.



Charts location 1



Charts location 2



Charts location 3

5. MEASURED VALUES DIAGRAMS

The following graphs show the diagrams of the physical quantities measured in the period between 03/11/2023 and 11/08/2024.

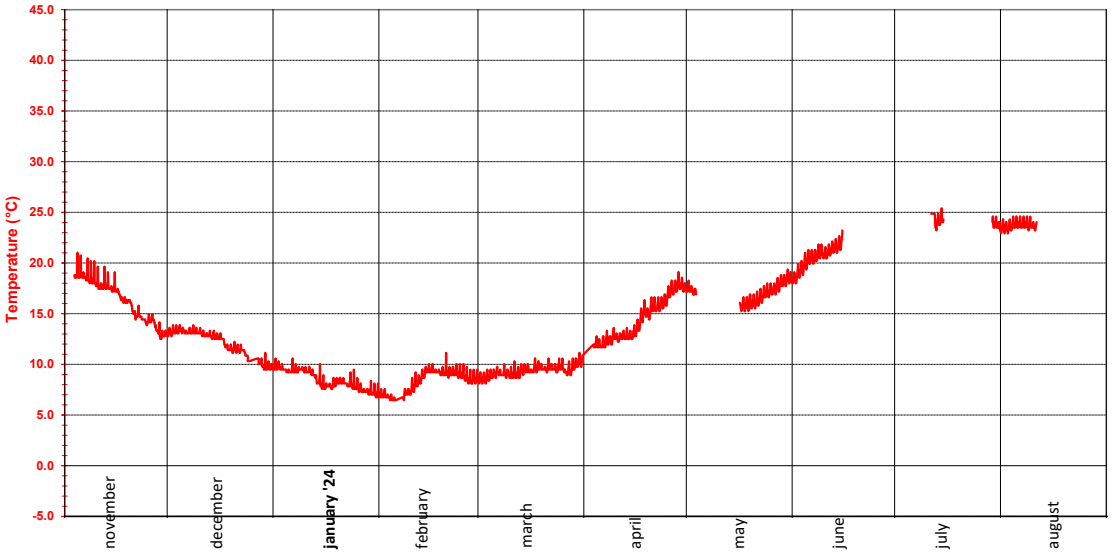
In the temperature sensors chart, the absolute value of the measured temperature is read in the ordinate, while the time reference expressed in months and days is displayed in the abscissa.

In the charts of the wire displacement transducers, the ordinate shows the recorded values adjusted with respect to the zero measurement (first acquisition = "offset"): in this way it is possible to directly evaluate the trend of the variations (relative measurements) regardless of the initial absolute value.

The current acquisition interval is 6 hours (4 daily acquisitions) for all installed instruments.

5.1. ENVIROMENTAL TEMPERATURE SENSORS

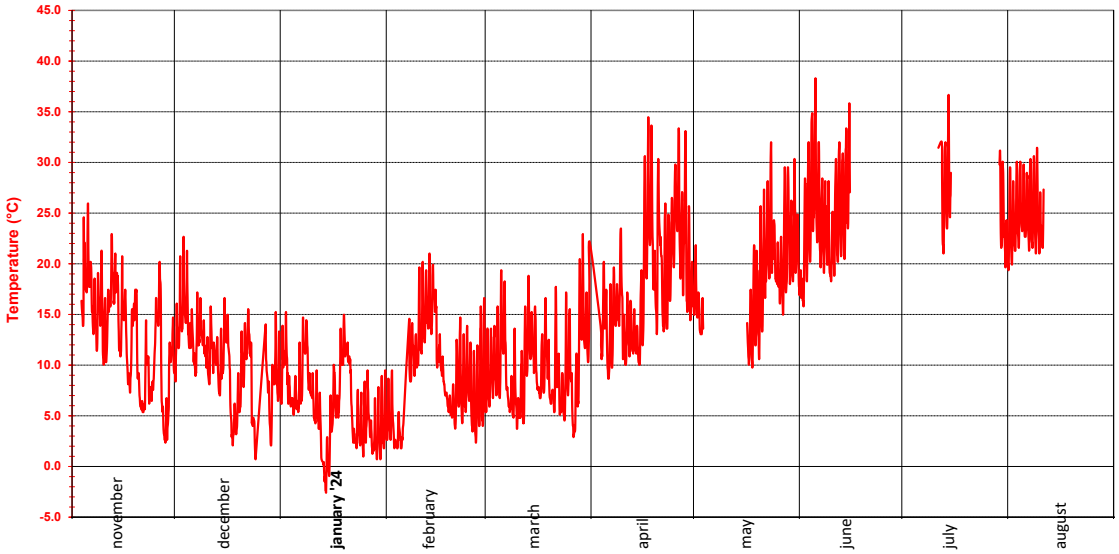
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Temperature Sensor T-1 (First Floor)
Monitoring period: 03/11/2023 - 11/08/2024



GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Temperature Sensor T-2 (First Floor)
Monitoring period: 03/11/2023 - 11/08/2024

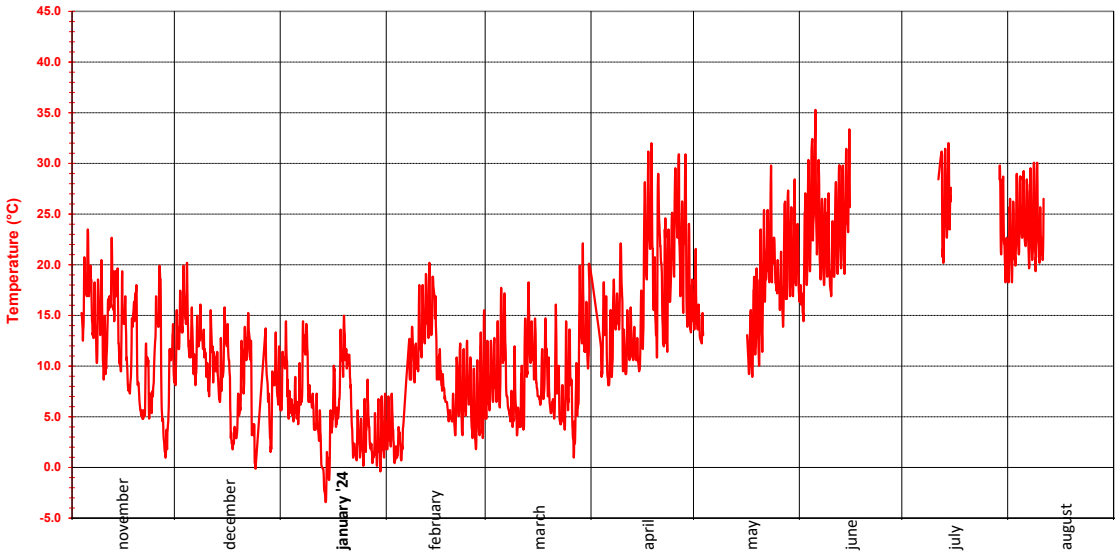
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF SOUTH SIDE
Temperature Sensor T-3

Monitoring period: 03/11/2023 - 11/08/2024



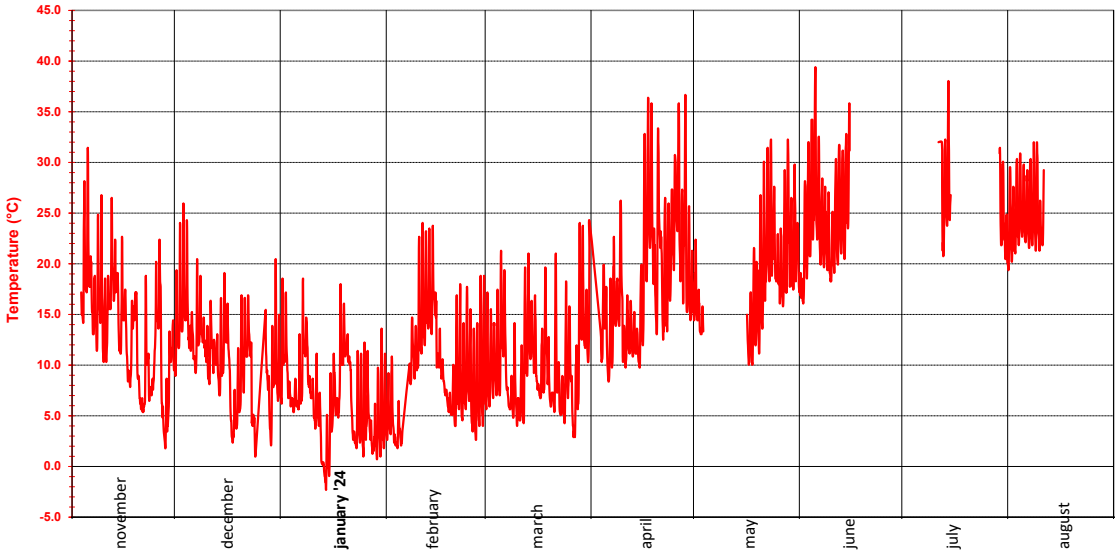
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF SOUTH SIDE
Temperature Sensor T-4

Monitoring period: 03/11/2023 - 11/08/2024



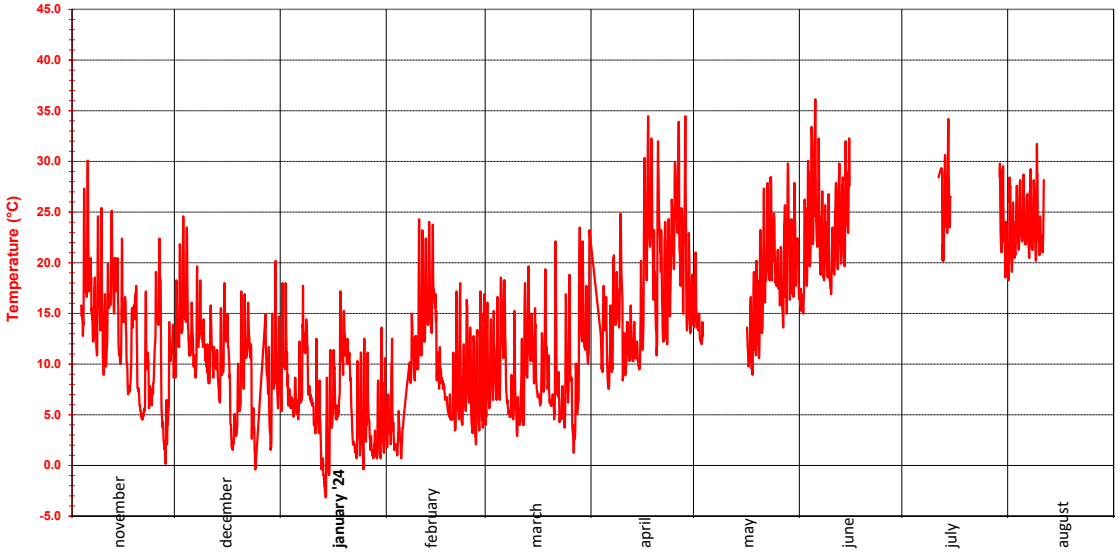
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF NORTH SIDE
Temperature Sensor T-5

Monitoring period: 03/11/2023 - 11/08/2024



GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF NORTH SIDE
Temperature Sensor T-6

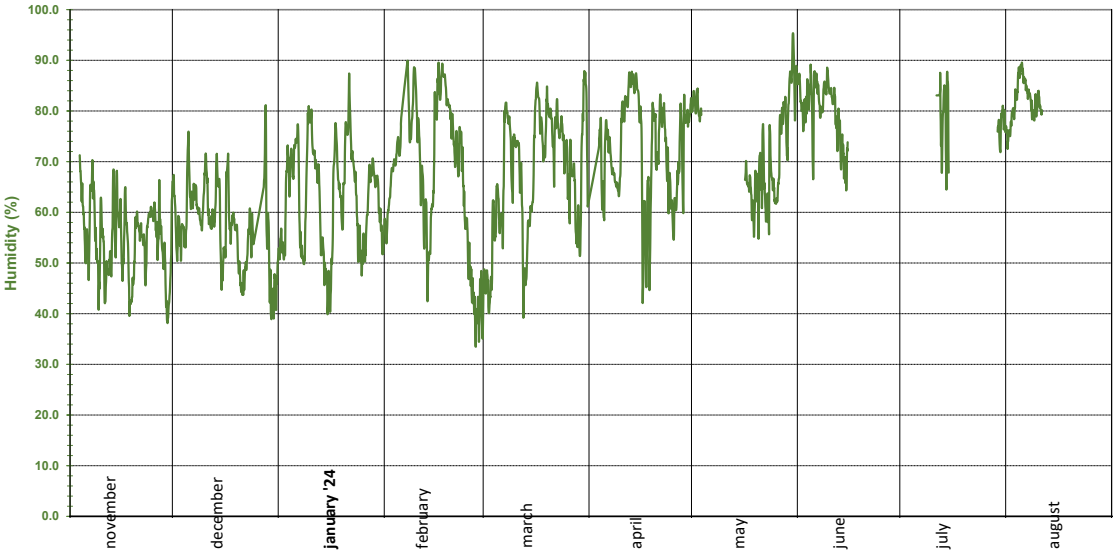
Monitoring period: 03/11/2023 - 11/08/2024



5.2. ENVIROMENTAL HUMIDITY SENSORS

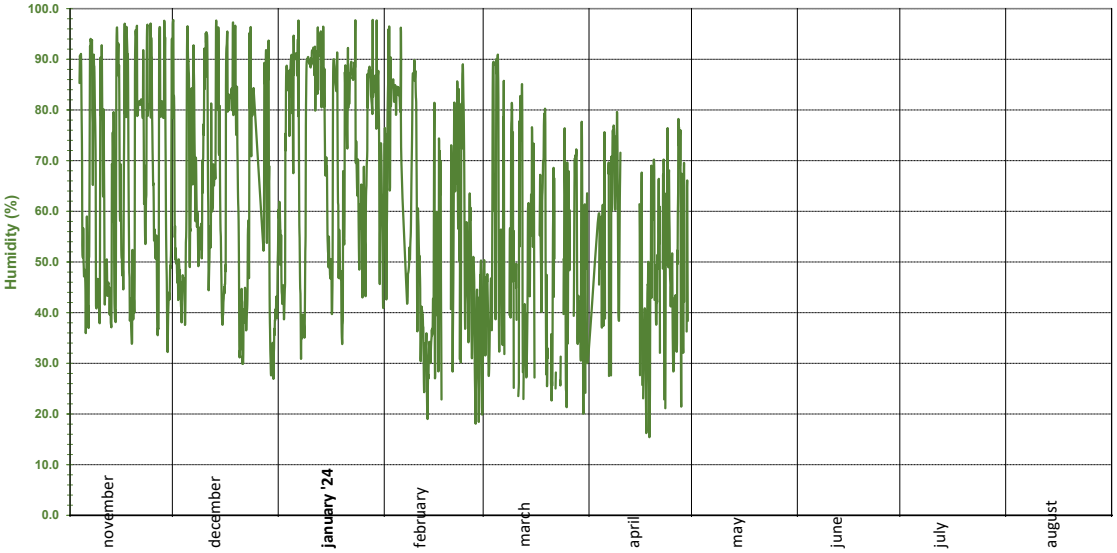
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Environmental Humidity Sensor UR-1 (First Floor)

Monitoring period: 03/11/2023 - 11/08/2024



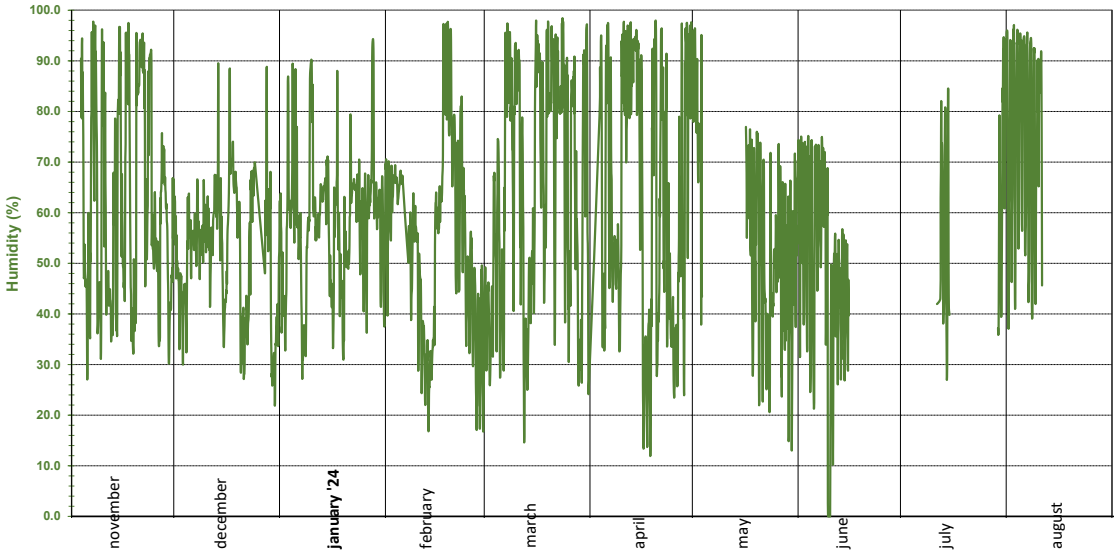
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Environmentale Humidity Sensor UR-2

Monitoring period: 03/11/2023 - 29/04/2024



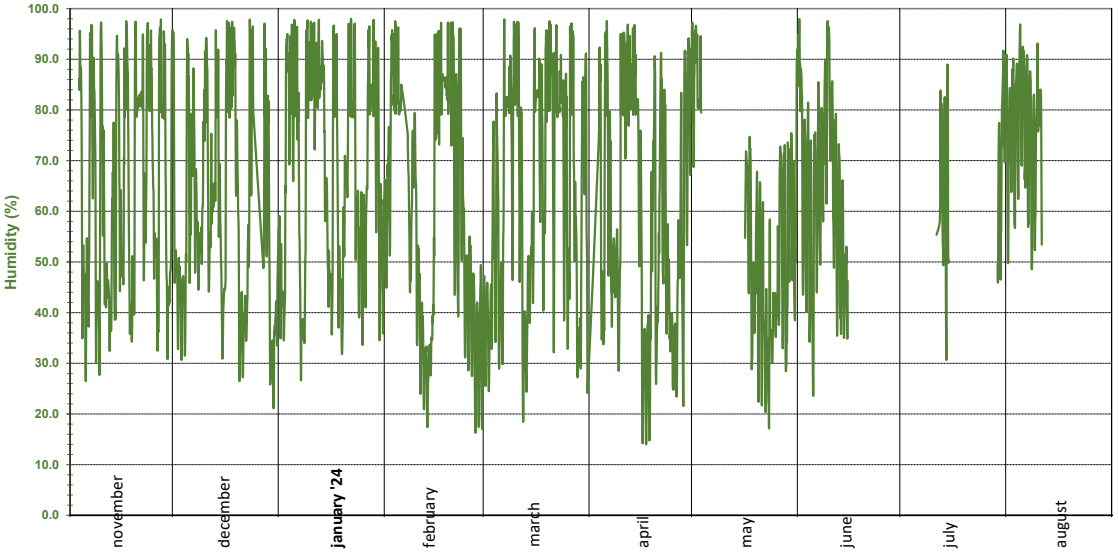
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Environmental Humidity Sensor UR-3

Monitoring period: 03/11/2023 - 11/08/2024



GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Environmental Humidity Sensor UR-4

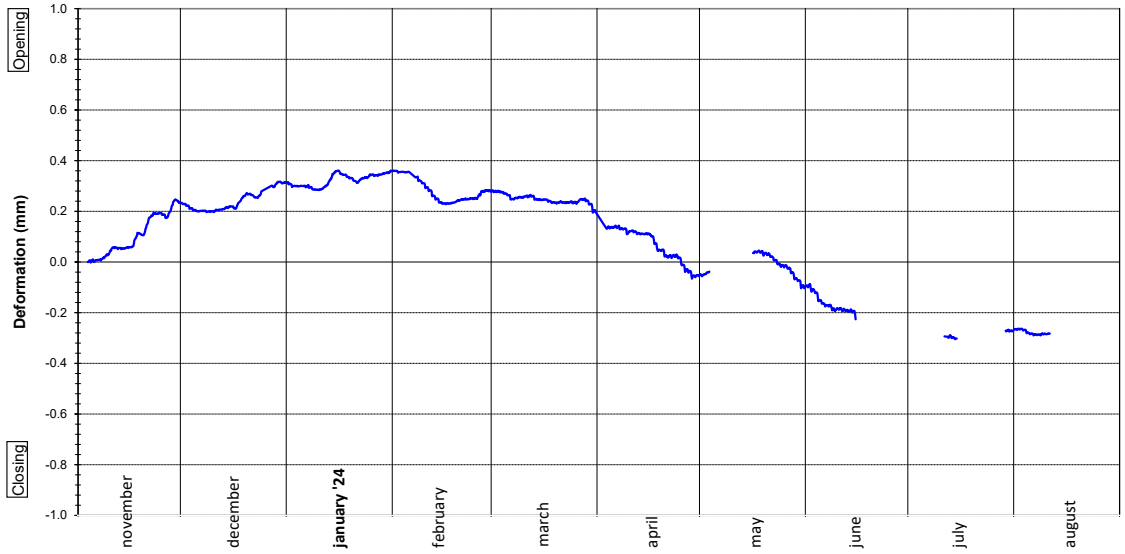
Monitoring period: 03/11/2023 - 11/08/2024



5.3. DISPLACEMENT TRANSDUCERS

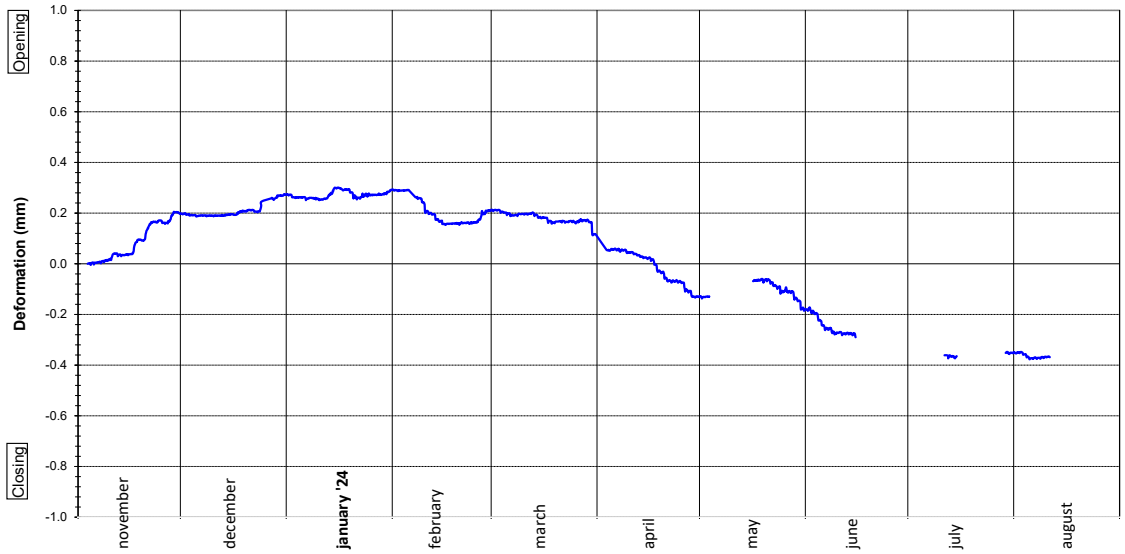
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Displacement Transducer Fe25-1

Monitoring period: 03/11/2023 - 11/08/2024



GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Displacement Transducer Fe25-2

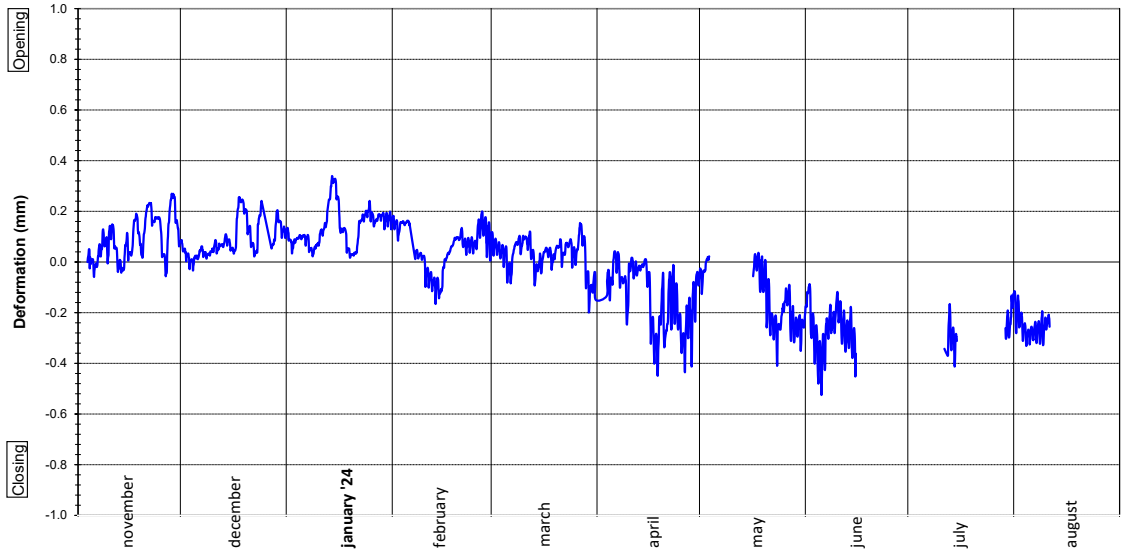
Monitoring period: 03/11/2023 - 11/08/2024



5.4. WDT - WIRE DISPLACEMENT TRANSDUCER

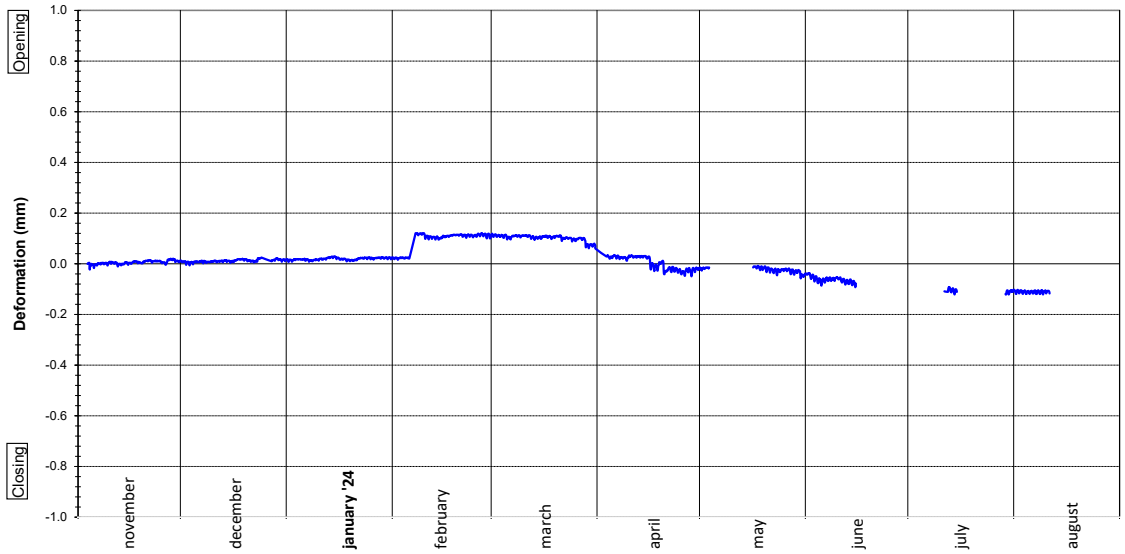
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF SOUTH SIDE
Wire Displacement Transducer WDT-1

Monitoring period: 03/11/2023 - 11/08/2024



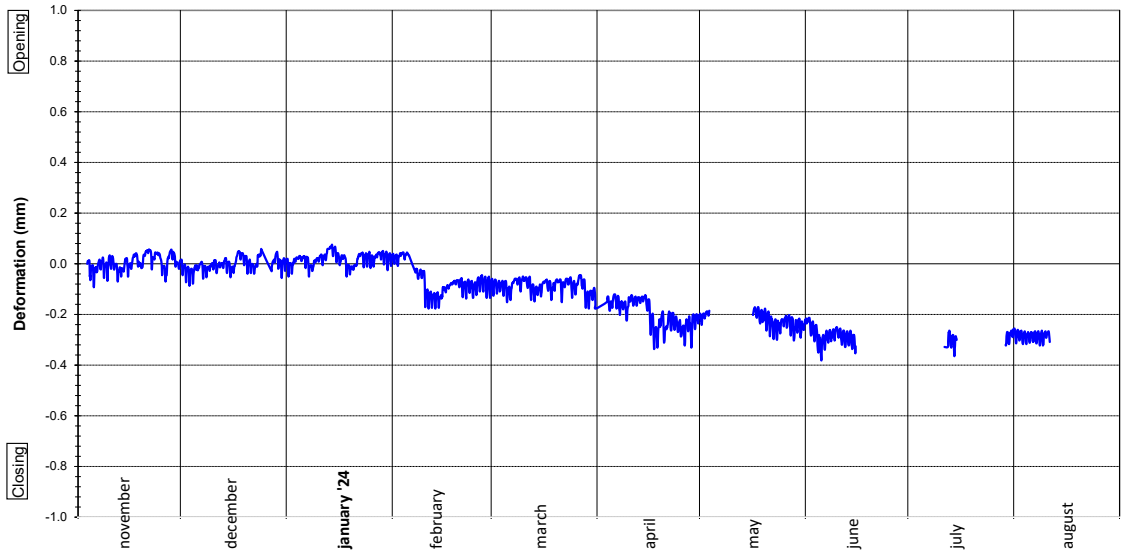
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF SOUTH SIDE
Wire Displacement Transducer WDT-2

Monitoring period: 03/11/2023 - 11/08/2024



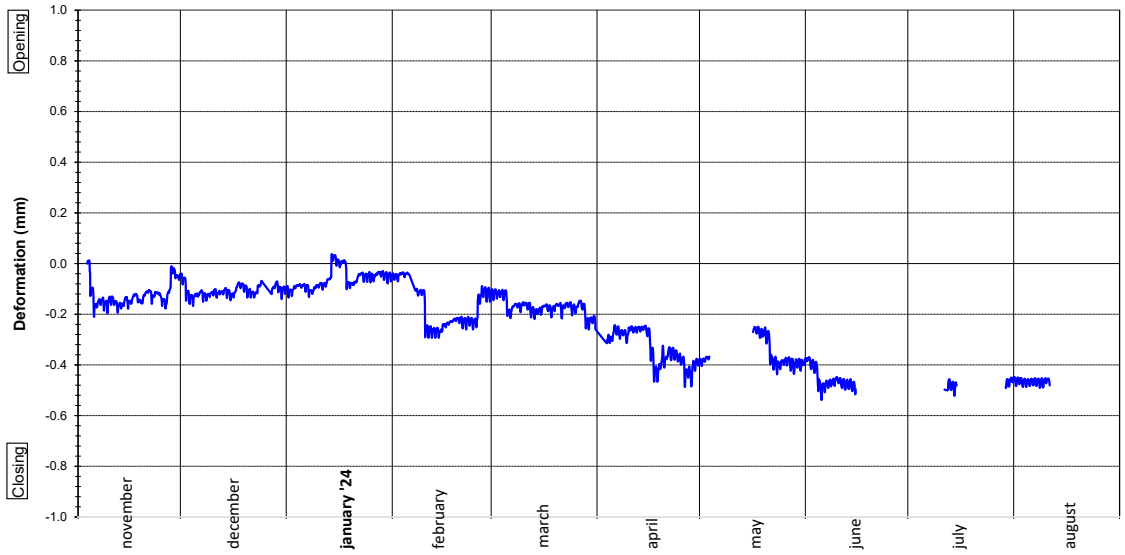
GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF NORTH SIDE
Wire Displacement Transducer WDT-3

Monitoring period: 03/11/2023 - 11/08/2024



GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF NORTH SIDE
Wire Displacement Transducer WDT-4

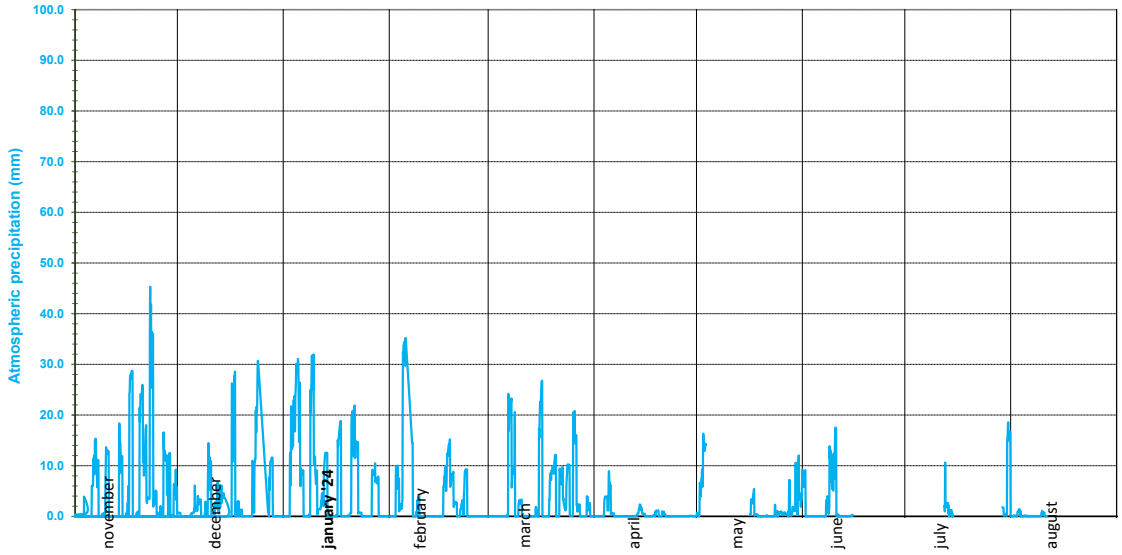
Monitoring period: 03/11/2023 - 11/08/2024



5.5. ATMOSPHERIC PRECIPITATION

GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Environmental Humidity Sensor UR-4

Monitoring period: 03/11/2023 - 11/08/2024



6. SUMMARY TABLES OF THE DETECTED DATA

The tables below show measurements performed and, in particular, the initial, final, minimum and maximum values measured over the entire registration period.

The difference between the initial and final values and the maximum excursion detected (difference between the maximum and minimum values) is also calculated.

TEMPERATURE SENSORS

Instrument	Initial value	Final value	Final - Initial values	Minimum value	Maximum value	Maximum excursion
Monitoring period: 03/11/2023 - 11/08/2024						
	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
T-1 (first floor)	18.8	24.0	**5.2**	6.5	25.4	**18.9**
T-2 (ground floor)	18.6	22.7	**4.1**	6.5	25.4	**18.9**
T-3 (int)	16.4	24.6	**8.2**	-2.6	38.3	**40.9**
T-4 (ext)	15.3	22.9	**7.7**	-3.4	35.3	**38.7**
T-5 (int)	17.2	29.3	**12.1**	-2.3	39.4	**41.7**
T-6 (ext)	15.8	28.2	**12.4**	-3.1	36.1	**39.3**

HUMIDITY SENSOR

Instrument	Initial value	Final value	Final - Initial values	Minimum value	Maximum value	Maximum excursion
Monitoring period: 03/11/2023 - 11/08/2024						
	[%]	[%]	[%]	[%]	[%]	[%]
UR-1	71.3	80.2	**8.9**	33.5	95.4	**61.9**
UR-2	85.3	60.0	**-25.3**	15.4	97.8	**82.4**
UR-3	90.5	67.8	**-22.6**	20.0	98.5	**78.5**
UR-4	86.1	53.4	**-32.7**	14.0	98.0	**84.0**

DISPLACEMENT TRANSDUCERS

Instrument	Initial value	Final value	Residual deformation	Minimum value	Maximum value	Maximum excursion
Monitoring period: 03/11/2023 - 11/08/2024						
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Fe25-1	0.000	-0.282	**-0.282**	-0.305	0.361	**0.666**
Fe25-2	0.000	-0.368	**-0.368**	-0.377	0.301	**0.678**

WIRE DISPLACEMENT TRANSDUCERS

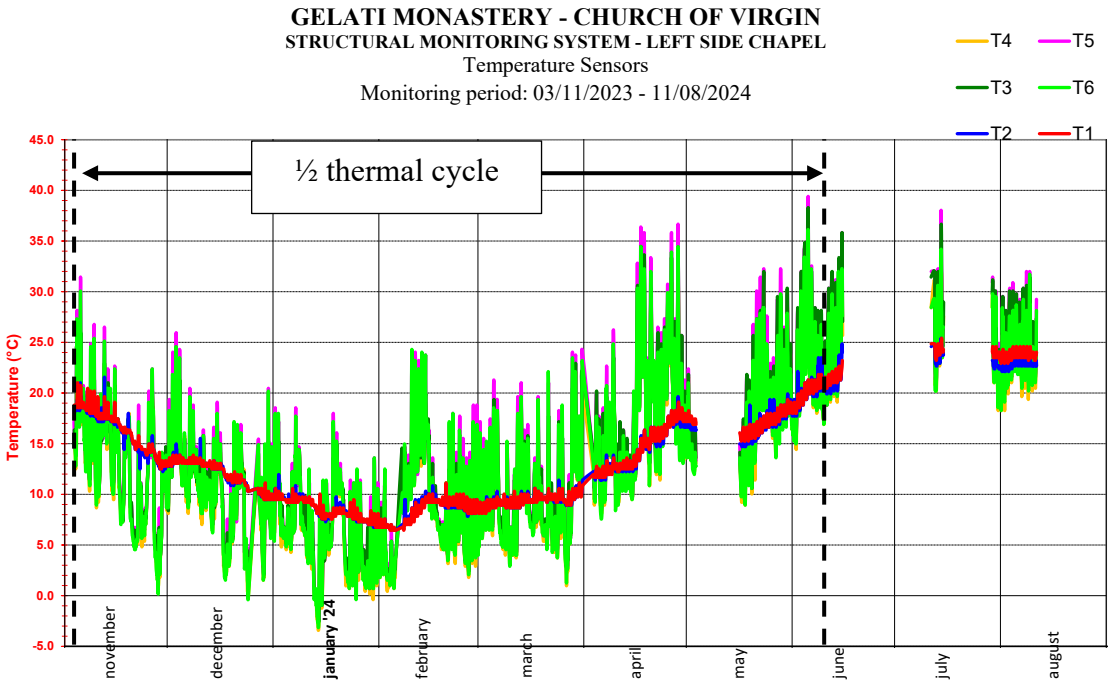
Instrument	Initial value	Final value	Residual deformation	Minimum value	Maximum value	Maximum excursion
Monitoring period: 03/11/2023 - 11/08/2024						
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
WDT-1	0.000	-0.225	**-0.225**	-0.525	0.340	**0.864**
WDT-2	0.000	-0.111	**-0.111**	-0.121	0.121	**0.242**
WDT-3	0.000	-0.308	**-0.308**	-0.381	0.076	**0.457**
WDT-4	0.000	-0.481	**-0.481**	-0.538	0.037	**0.576**

7. RESULTS

The monitoring, which began in November 2023, currently covers a time range of approximately 9 months, within which it is possible to observe the behavior of the monitored lesions over the first half of the first thermal cycle in progress.

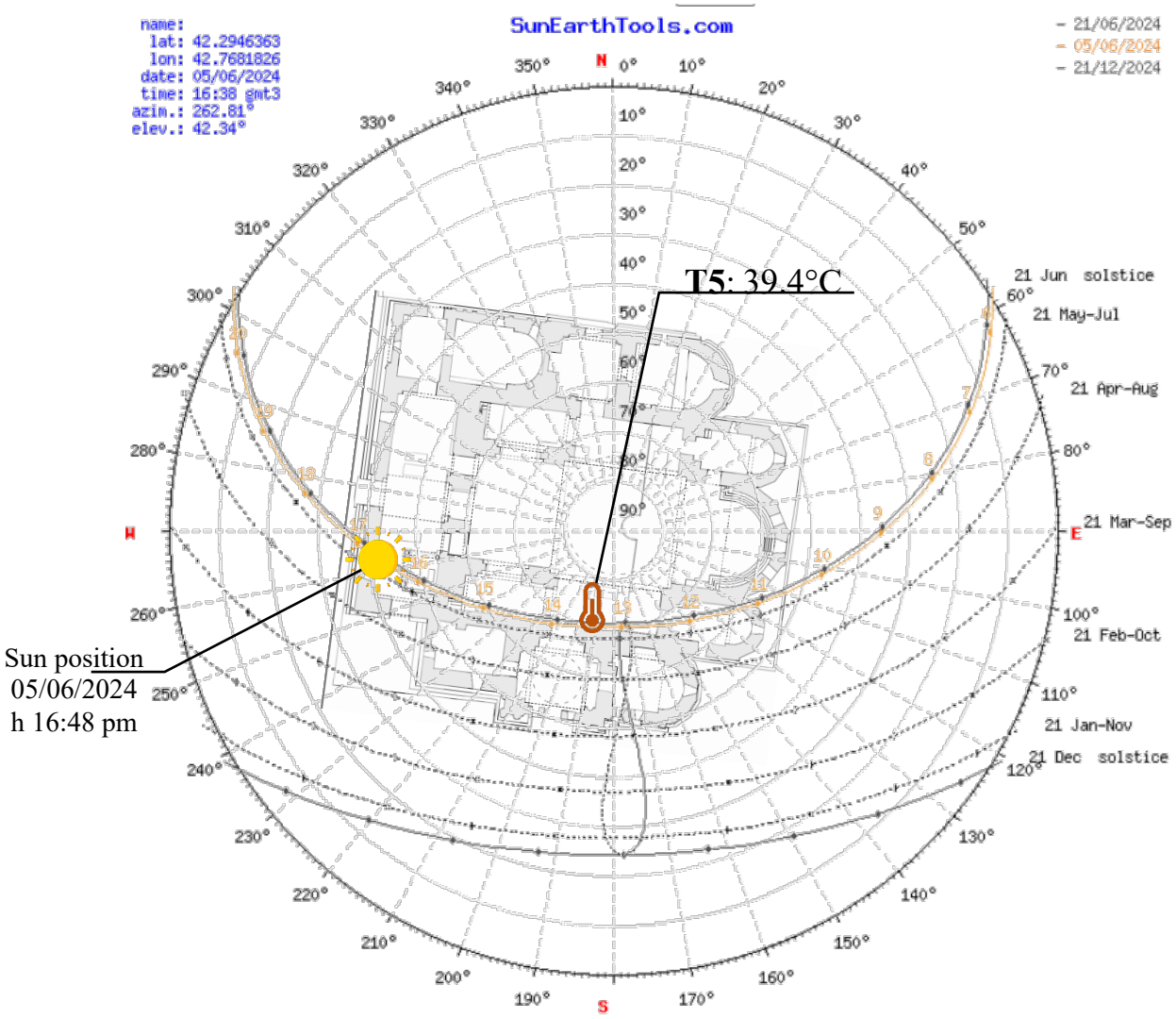
7.1. TEMPERATURE SENSORS

The graph below shows the daily temperature trends, internal and external to the church, recorded during the monitoring period on the entire complex.



The graph also shows the high daily thermal excursion measured by the attic sensors (T3, T4, T5, T6) while inside the chapel, in location 1, the temperature remained more stable (T1, T2).

The highest temperature, 39.4°C, was detected on 05/06/2024 at 16:48 pm by the sensor T5 installed in the attic on the north side, (location 3) , when the position of the sun was as depicted in the following image, which represents the path of the sun during the year and on the date of interest.

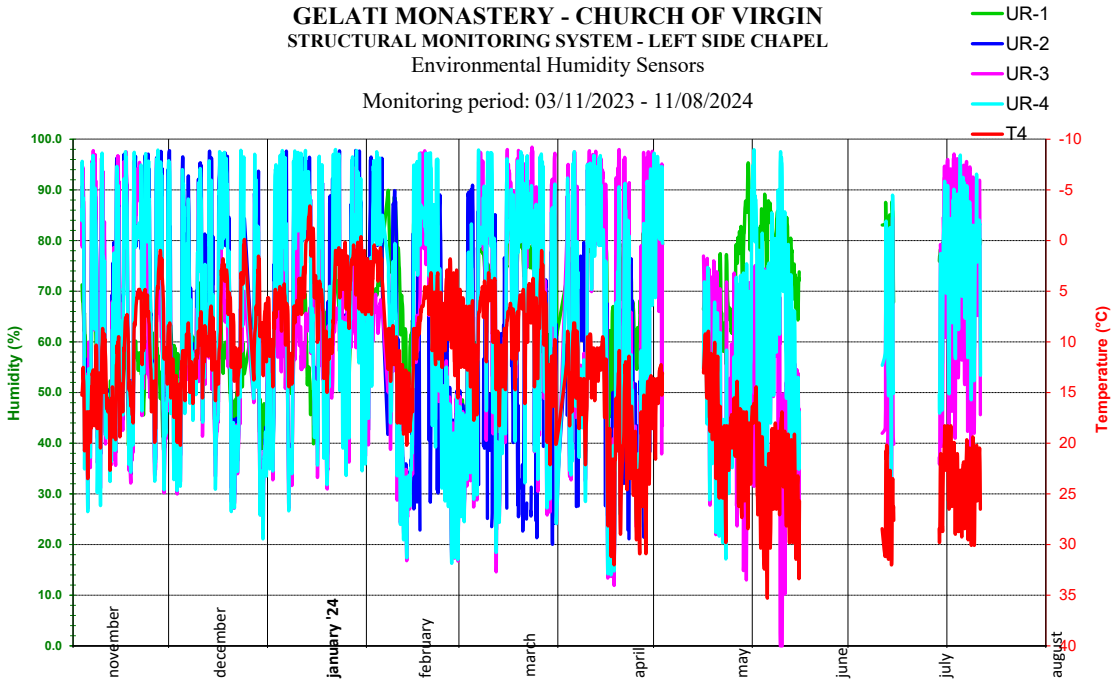


The lowest temperature, -3.4°C, was detected on 14/01/2024 at 05:35 am by the sensor T4 installed from the attic on the internal façade on the south side.

Instrument	Initial value	Final value	Final - Initial values	Minimum value	Maximum value	Maximum excursion	Mean	Median	Standard deviation
Monitoring period: 03/11/2023 - 11/08/2024									
	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
T-1 (first floor)	18.8	24.0	**5.2**	6.5	25.4	**18.9**	13.4	12.5	4.92
T-2 (ground floor)	18.6	22.7	**4.1**	6.5	25.4	**18.9**	13.2	12.5	4.76
T-3 (int)	16.4	24.6	**8.2**	-2.6	38.3	**40.9**	13.4	12.2	7.43
T-4 (ext)	15.3	22.9	**7.7**	-3.4	35.3	**38.7**	12.7	11.7	7.29
T-5 (int)	17.2	29.3	**12.1**	-2.3	39.4	**41.7**	13.8	12.6	7.54
T-6 (ext)	15.8	28.2	**12.4**	-3.1	36.1	**39.3**	13.1	12.2	7.29

7.2. ENVIROMENTAL HUMIDITY SENSORS

The following graphs show the trends in humidity outside and inside the church and the attic compared with the temperature.

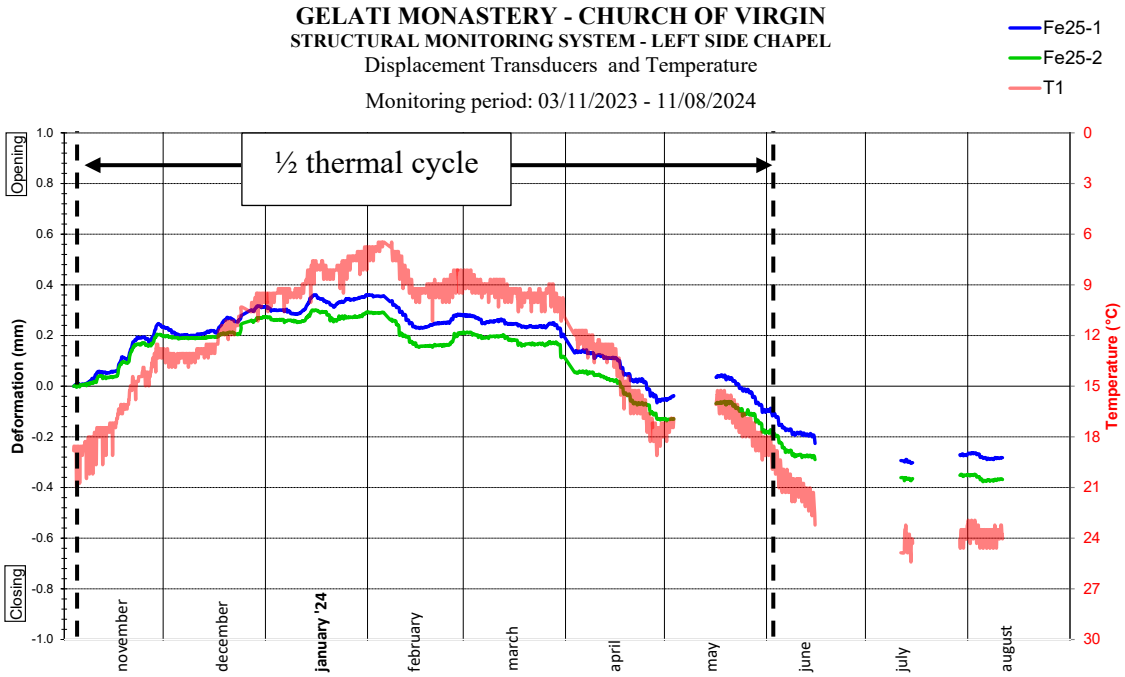


Instrument	Initial value	Final value	Final - Initial values	Minimum value	Maximum value	Maximum excursion	Mean	Median	Standard deviation
Monitoring period: 03/11/2023 - 11/08/2024									
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
UR-1	71.3	80.2	**8.9**	33.5	95.4	**61.9**	67	67	12.7
UR-2	85.3	60.0	**-25.3**	15.4	97.8	**82.4**	59	58	19.3
UR-3	90.5	67.8	**-22.6**	20.0	98.5	**78.5**	64	65	21.0
UR-4	86.1	53.4	**-32.7**	14.0	98.0	**84.0**	67	67	12.7
UR-1	71.3	80.2	**8.9**	33.5	95.4	**61.9**	59	58	19.3
UR-2	85.3	0.0	**-85.3**	15.4	97.8	**82.4**	64	65	21.0

7.3. DISPLACEMENT TRANSDUCERS

The next graph compares the trends of the displacement sensors with the ambient temperatures.

Temperature has been plotted with the direction increasing downwards in order to show more clearly the influence it exerts on the movements of the lesions.



By observing the overall behaviour of the two transducers, it is possible to observe that the trend of the monitored lesions appears to be determined by the natural correlation between the movements and the thermal variations.

During the months in which temperatures decrease, we witness a progressive tendency towards opening, while, in correspondence with the increase in temperatures, a progressive closing of the joints can be observed.

To verify whether there is an evolutionary trend of the lesions, it is necessary to wait for the conclusion of the first thermal cycle, in November 2024.

The following tables show the values recorded halfway through the first thermal cycle, when temperatures return for the first time to the initial levels

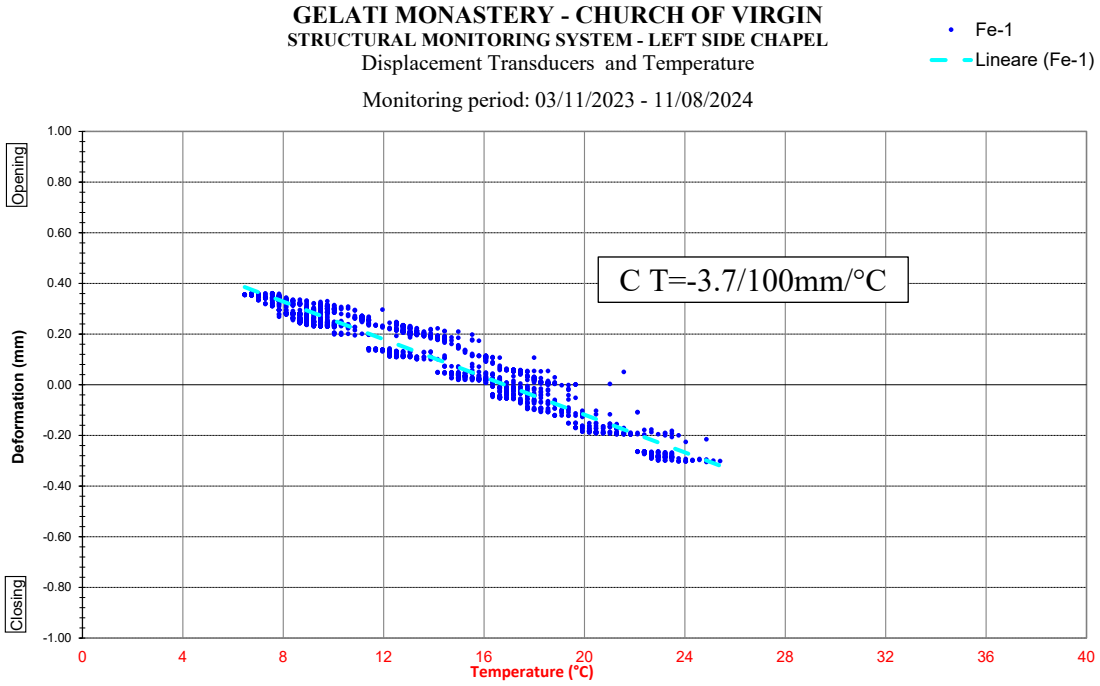
LEFT SIDE CHAPEL

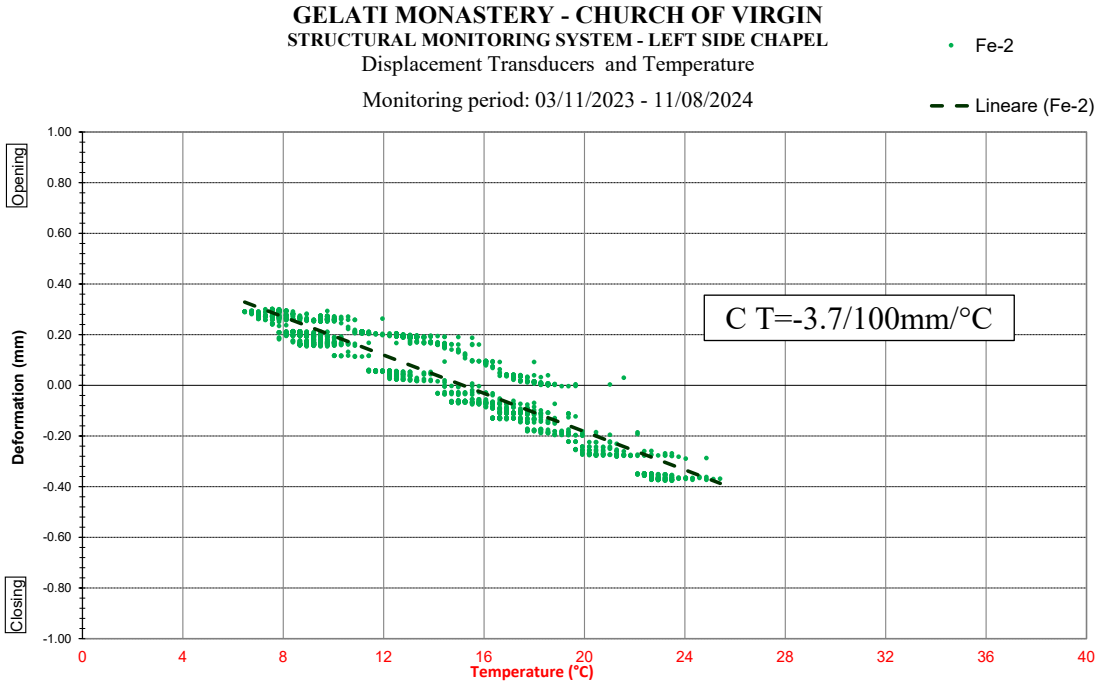
Monitoring period: 11/2023 - 06/2024

Instrument	Initial value	Final value	Excursion Initial-Final values	Minimum value	Maximum value	Maximum excursion
	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
T-1 (first floor)	18.8	18.8	**0.0**	6.5	21.0	**14.6**

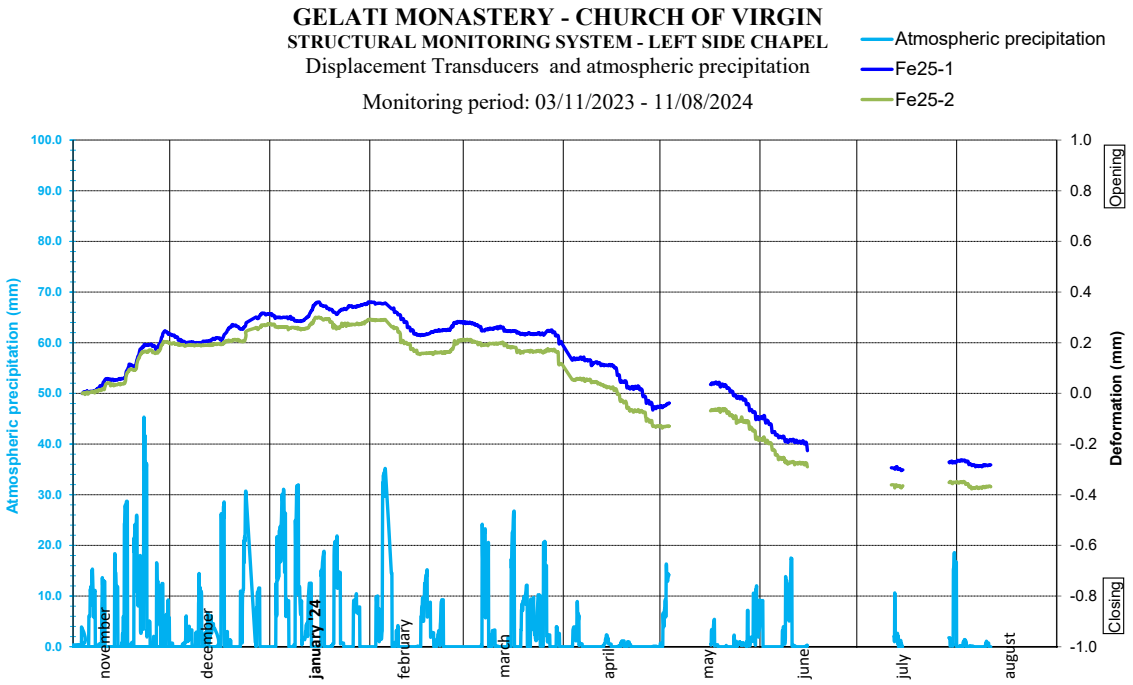
Instrument	Initial value	Final value	Residual deformation	Minimum value	Maximum value	Maximum excursion
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
Fe25-1	0.000	-0.099	**-0.099**	-0.103	0.361	**0.464**
Fe25-2	0.000	-0.183	**-0.183**	-0.185	0.301	**0.486**

This behavior is clearly visible by analyzing the evolution of the displacement as a function of temperature in the following graph, where the thermal coefficient is reported, expressed in hundredths of a millimeter per degree centigrade of variation.



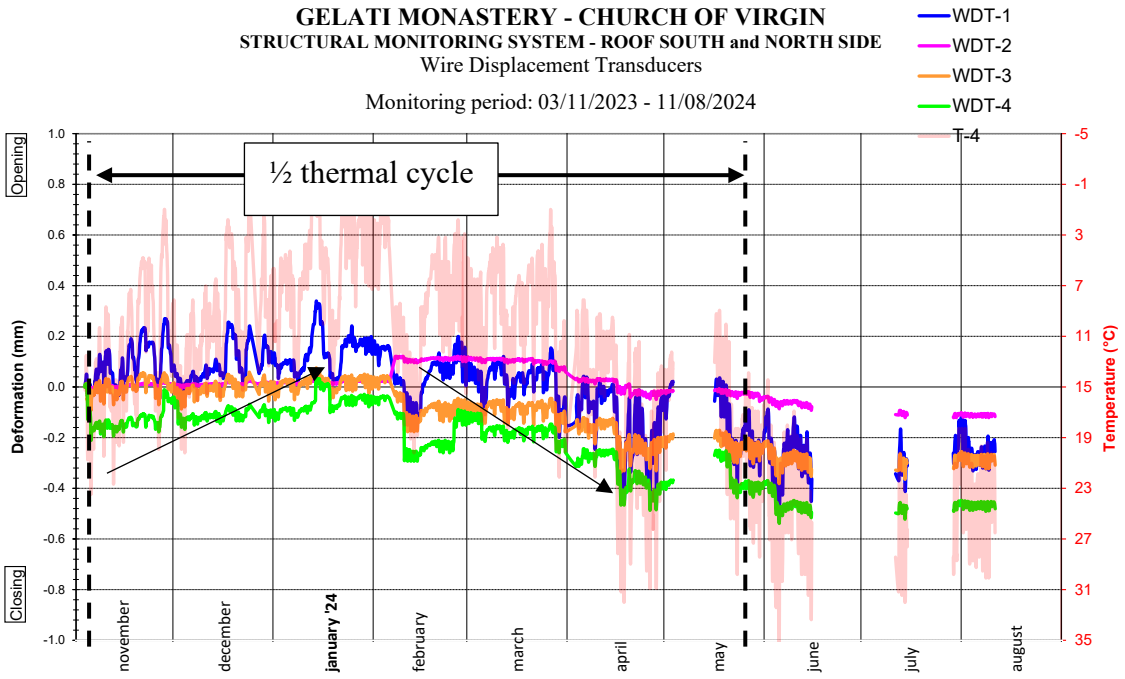


Below are the trends of the displacement transducers compared with the precipitation measured in the vicinity of the site, from which no particular connection between the quantity of rainfall and the opening/closing of the lesions is evident.



7.4. WIRE DISPLACEMENT TRANSDUCER

At last we analyze the behavior of the wire transducers installed in the attic of the church. The following graph shows the acquisitions relating to the wire displacement transducers compared with the temperature trend.



From the graphs it is clear that, up to now, it exists a correlation between the thermal variations and the recorded movements. During the phase of temperature increase, until January, the instruments measure a closure, which corresponds to a relative approach of the controlled points. During the period in which the temperatures tend to decrease, starting from February, a phase of recovery of the undergone movement is observed.

The following tables show the values recorded halfway through the first thermal cycle, when temperatures return for the first time to the initial levels.

ROOF SOUTH SIDE

Monitoring period: 11/2023 - 05/2024

Instrument	Initial value	Final value	Excursion Initial-Final values	Minimum value	Maximum value	Maximum excursion
	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
T-4 (ext)	19.1	19.1	**0.0**	-3.4	32.0	**35.4**

Instrument	Initial value	Final value	Residual deformation	Minimum value	Maximum value	Maximum excursion
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
WDT-1	-0.006	-0.084	**-0.079**	-0.449	0.340	**0.789**
WDT-2	-0.004	-0.023	**-0.018**	-0.049	0.121	**0.170**

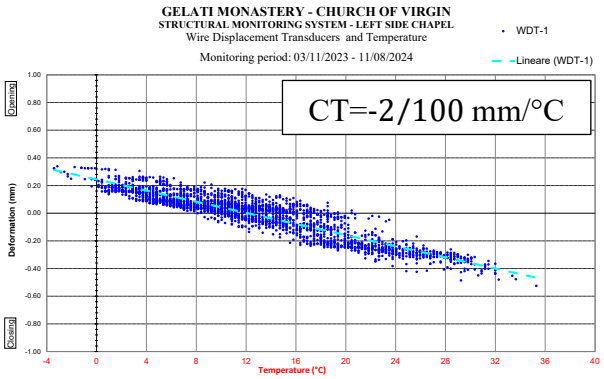
ROOF SOUTH SIDE

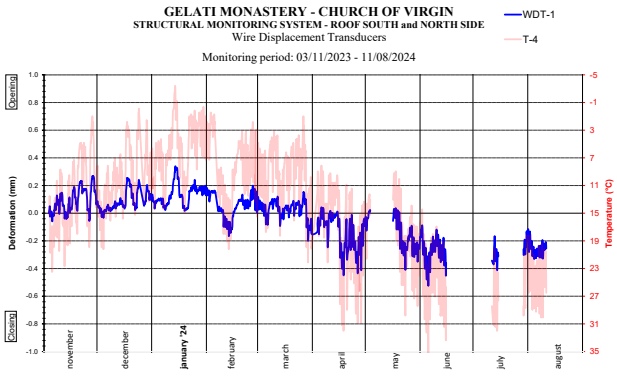
Monitoring period: 11/2023 - 05/2024

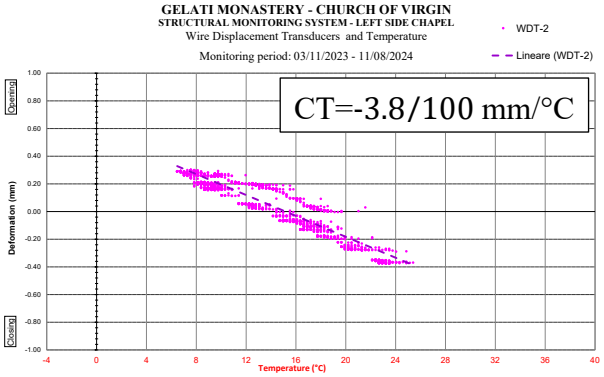
Instrument	Initial value	Final value	Excursion Initial-Final values	Minimum value	Maximum value	Maximum excursion
	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
T-6 (ext)	20.5	20.5	**0.0**	-3.1	30.4	**33.5**

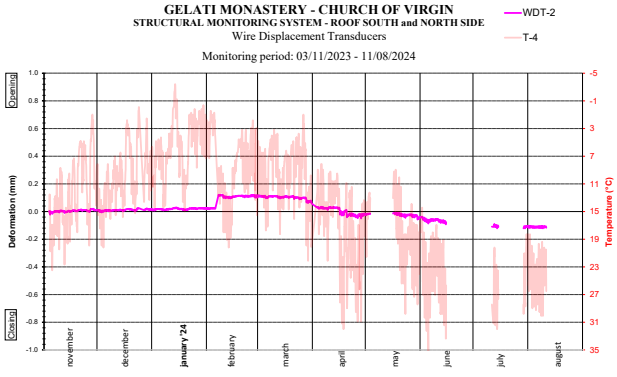
Instrument	Initial value	Final value	Residual deformation	Minimum value	Maximum value	Maximum excursion
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
WDT-3	-0.050	-0.208	**-0.157**	-0.280	0.076	**0.356**
WDT-4	-0.033	-0.340	**-0.307**	-0.384	0.037	**0.421**

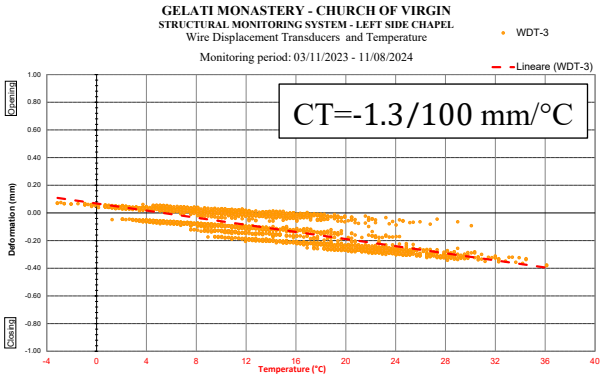
To improve the understanding of the behavior of the transducers, we analyze the evolution of the displacement as a function of temperature in the following graph, where the thermal coefficient is reported, expressed in hundredths of a millimeter per degree centigrade of variation.

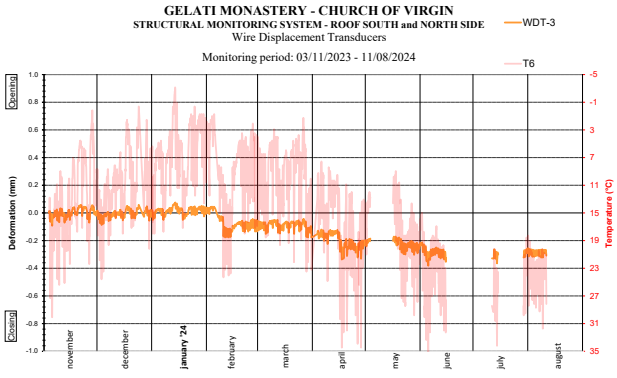


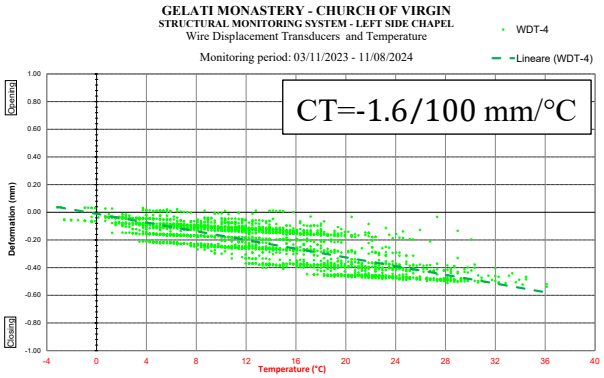


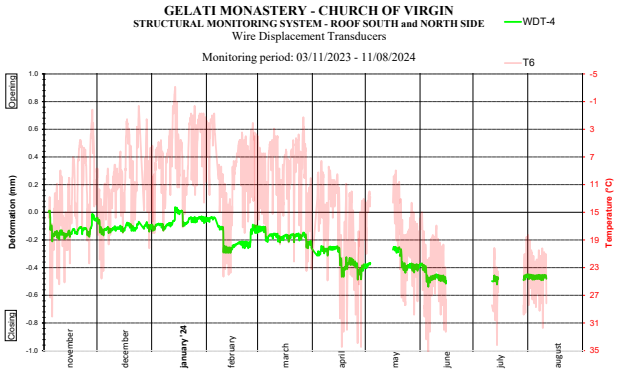












The charts show clear downward trend, confirming the inverse relationship between temperature and deformation, which means that the deformation decreases as the temperature increases.

7.5. CORRELATION MATRIX

The following table represent a correlation matrix: each cell in the in the table shows the degree of interdependence between two variables.
Correlation values range from -1 to 1, where values close to 1 indicate a strong positive correlation, values close to -1 indicate a strong negative correlation, and values close to 0 suggest no correlation.

	T-1	T-2	T-3	T-4	T-5	T-6	Fe25-1	Fe25-2	WDT-1	WDT-2	WDT-3	WDT-4	UR-1	UR-3	UR-4	Rain
T-1	1	0.996	0.816	0.809	0.787	0.774	-0.968	-0.934	-0.721	-0.843	-0.694	-0.774	0.317	0.055	0.009	-0.121
T-2	0.996	1	0.830	0.824	0.799	0.786	-0.966	-0.931	-0.741	-0.839	-0.699	-0.779	0.320	0.038	-0.004	-0.122
T-3	0.816	0.830	1	0.996	0.988	0.979	-0.832	-0.828	-0.930	-0.664	-0.856	-0.853	0.301	-0.292	-0.366	-0.290
T-4	0.809	0.824	0.996	1	0.984	0.980	-0.823	-0.818	-0.926	-0.658	-0.845	-0.843	0.282	-0.311	-0.389	-0.298
T-5	0.787	0.799	0.988	0.984	1	0.993	-0.796	-0.793	-0.900	-0.639	-0.839	-0.827	0.257	-0.334	-0.421	-0.306
T-6	0.774	0.786	0.979	0.980	0.993	1	-0.781	-0.776	-0.886	-0.628	-0.824	-0.810	0.229	-0.357	-0.452	-0.324
Fe25-1	-0.968	-0.966	-0.832	-0.823	-0.796	-0.781	1	0.992	0.807	0.788	0.819	0.881	-0.457	-0.100	-0.045	0.154
Fe25-2	-0.934	-0.931	-0.828	-0.818	-0.793	-0.776	0.992	1	0.831	0.756	0.870	0.917	-0.497	-0.101	-0.036	0.179
WDT-1	-0.721	-0.741	-0.930	-0.926	-0.900	-0.886	0.807	0.831	1	0.582	0.928	0.917	-0.490	0.165	0.228	0.256
WDT-2	-0.843	-0.839	-0.664	-0.658	-0.639	-0.628	0.788	0.756	0.582	1	0.514	0.580	-0.236	0.008	-0.028	0.071
WDT-3	-0.694	-0.699	-0.856	-0.845	-0.839	-0.824	0.819	0.870	0.928	0.514	1	0.968	-0.512	0.094	0.193	0.302
WDT-4	-0.774	-0.779	-0.853	-0.843	-0.827	-0.810	0.881	0.917	0.917	0.580	0.968	1	-0.544	0.012	0.092	0.235
UR-1	0.317	0.320	0.301	0.282	0.257	0.229	-0.457	-0.497	-0.490	-0.236	-0.512	-0.544	1	0.524	0.564	0.102
UR-3	0.055	0.038	-0.292	-0.311	-0.334	-0.357	-0.100	-0.101	0.165	0.008	0.094	0.012	0.524	1	0.826	0.279
UR-4	0.009	-0.004	-0.366	-0.389	-0.421	-0.452	-0.045	-0.036	0.228	-0.028	0.193	0.092	0.564	0.826	1	0.405
Rain	-0.121	-0.122	-0.290	-0.298	-0.306	-0.324	0.154	0.179	0.256	0.071	0.302	0.235	0.102	0.279	0.405	1

As we already assessed, the matrix confirmed that the temperature variables are highly positively correlated with each other, with correlation values to close to 1.

The temperature variables are also strongly negatively correlated with Fe25-1 and Fe25-2.

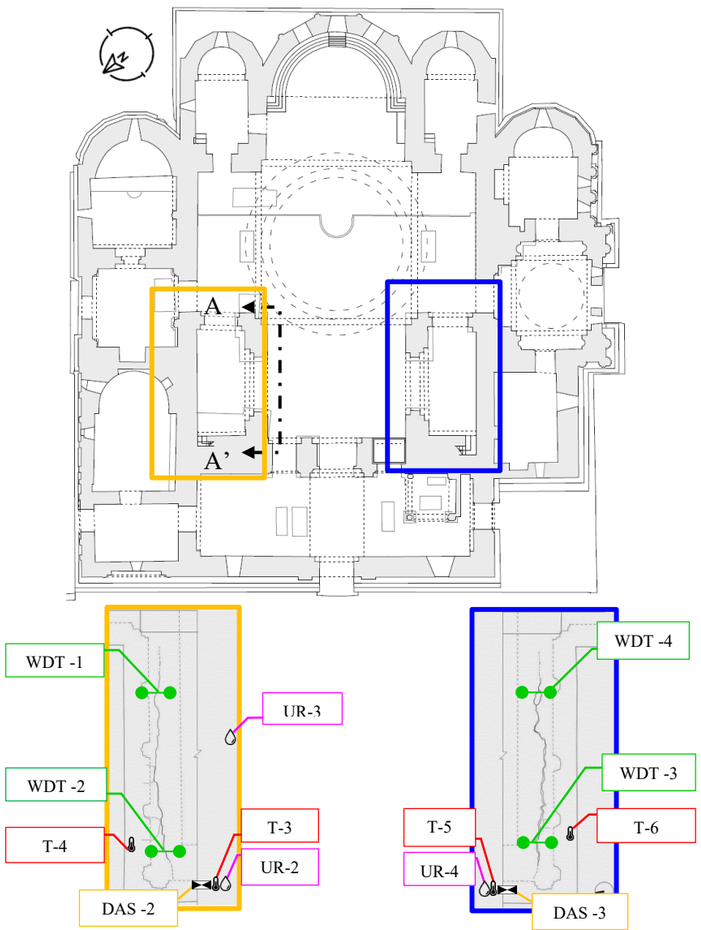
The displacement transducers Fe25-1 and Fe25-2 are almost perfectly positively correlated (0.992)

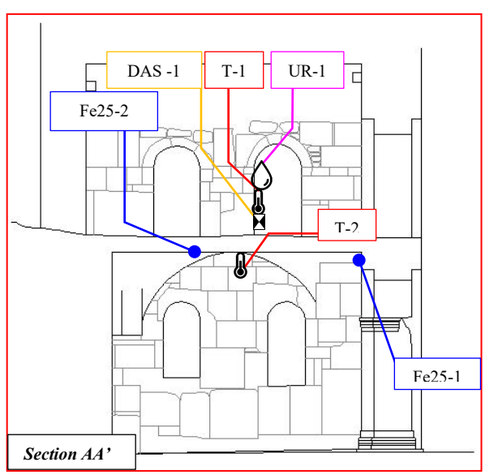
WDT sensors show strong positive correlations among themselves, especially between WDT-3 and WDT-4 (0.968). They also have strong negative correlations with the T variables, especially WDT-1 with the temperature sensors T-3 and T-4.

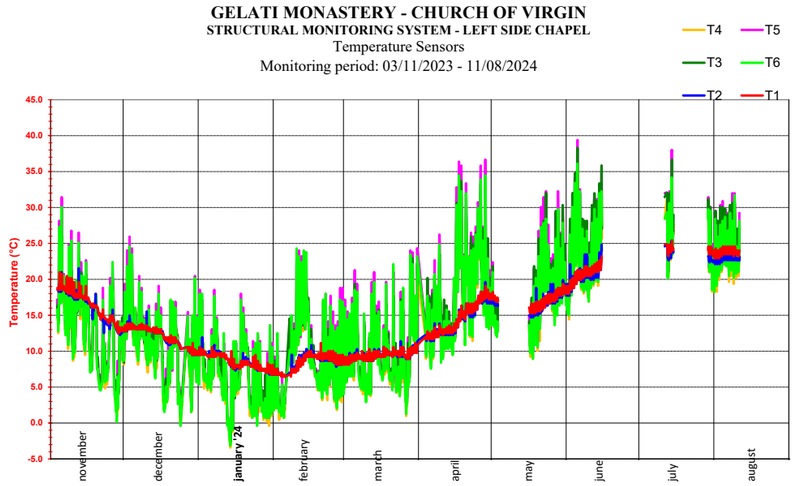
Analyzing the humidity values, we can see that UR-1 shows some positive correlation with UR-3 and UR-4 but UR variables generally have weak correlations with the other groups (T, Fe25, and WDT).

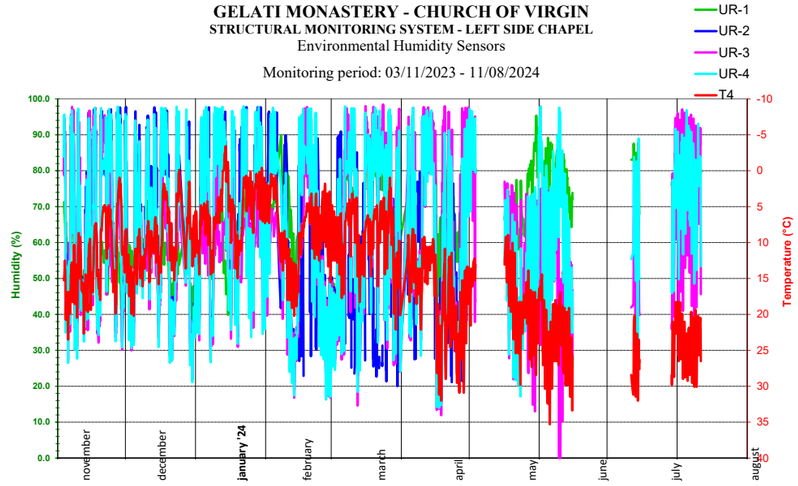
Atmospheric precipitation shows weak correlations with any other variable, confirming the limited influence it exerted on the structures during the 9 months of monitoring.

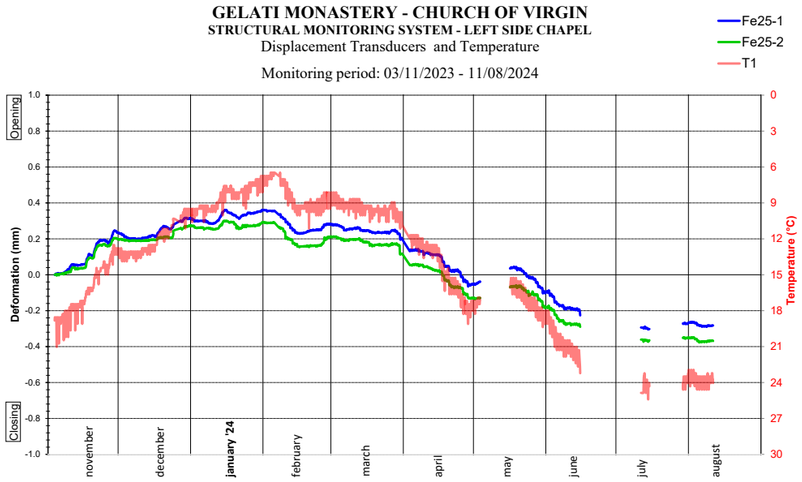
7.6. OVERVIEW

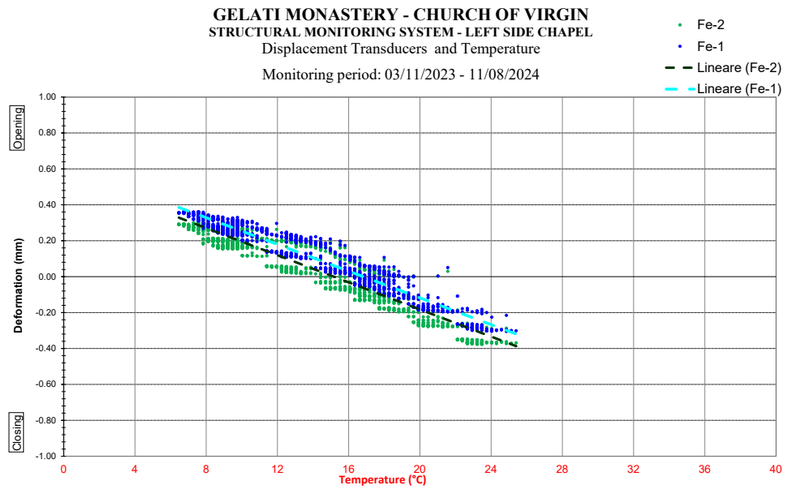

A
A'
WDT -1
UR-3
WDT -2
T-4
T-3
UR-2
DAS -2
WDT -4
WDT -3
T-5
T-6
UR-4
DAS -3

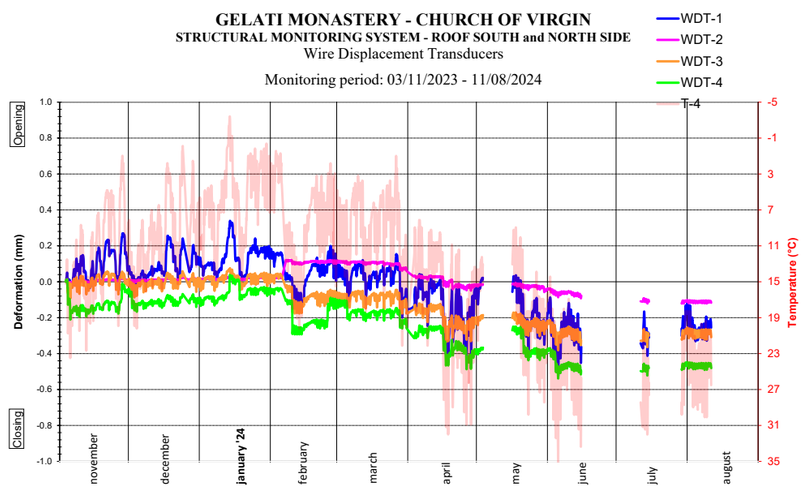

DAS -1
T-1
UR-1
Fe25-2
T-2
Fe25-1
Section AA'

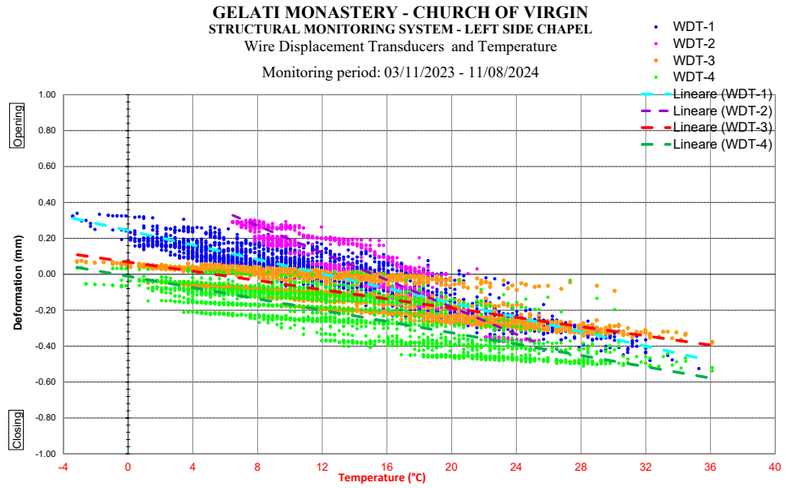

GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Temperature Sensors
Monitoring period: 03/11/2023 - 11/08/2024
T4
T5
T3
T6
T2
T1
Temperature (°C)
november
december
january '24
febraury
march
april
may
june
july
august


GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Environmental Humidity Sensors
Monitoring period: 03/11/2023 - 11/08/2024
UR-1
UR-2
UR-3
UR-4
T4
Humidity (%)
Temperature (°C)
november
december
january '24
febraury
march
april
may
june
july
august


GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Displacement Transducers and Temperature
Monitoring period: 03/11/2023 - 11/08/2024
Fe25-1
Fe25-2
T1
Opening
Closing
Deformation (mm)
Temperature (°C)
november
december
january '24
febraury
march
april
may
june
july
august


GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Displacement Transducers and Temperature
Monitoring period: 03/11/2023 - 11/08/2024
Fe-2
Fe-1
Lineare (Fe-2)
Lineare (Fe-1)
Opening
Closing
Deformation (mm)
Temperature (°C)


GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - ROOF SOUTH and NORTH SIDE
Wire Displacement Transducers
Monitoring period: 03/11/2023 - 11/08/2024
WDT-1
WDT-2
WDT-3
WDT-4
T-4
Opening
Closing
Deformation (mm)
Temperature (°C)
november
december
january '24
febraury
march
april
may
june
july
august


GELATI MONASTERY - CHURCH OF VIRGIN
STRUCTURAL MONITORING SYSTEM - LEFT SIDE CHAPEL
Wire Displacement Transducers and Temperature
Monitoring period: 03/11/2023 - 11/08/2024
WDT-1
WDT-2
WDT-3
WDT-4
Lineare (WDT-1)
Lineare (WDT-2)
Lineare (WDT-3)
Lineare (WDT-4)
Opening
Closing
Deformation (mm)
Temperature (°C)