Politecnico di Torino
Department of Structural, Geotechnical and Building Engineering

DATA FUSION FOR STRUCTURAL HEALTH MONITORING (SHM) FOR DAMAGE DETECTION

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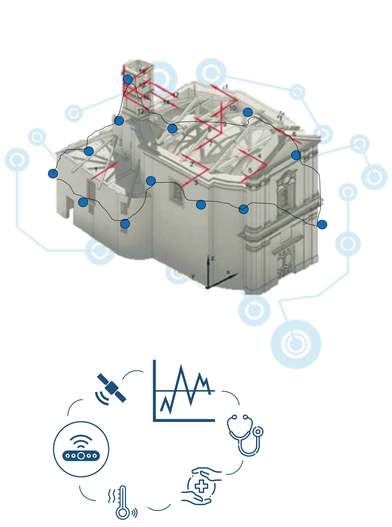
STRUCTURAL HEALTH MONITORING (SHM)

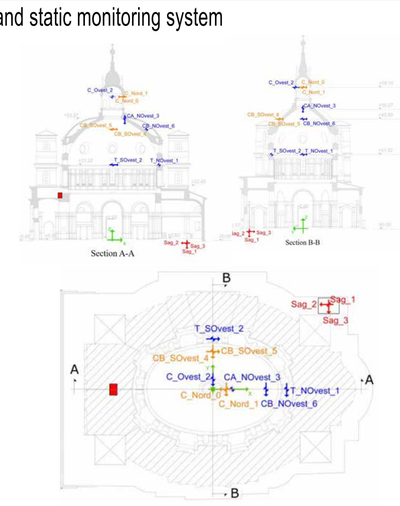


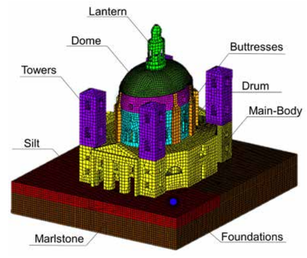
In recent years, earthquakes and other catastrophic events have increasingly highlighted the fragility of the built environment. Infrastructures, buildings, and entire urban areas have proved particularly vulnerable to natural phenomena, whether caused by climate change (such as floods and landslides) or earthquakes, but also to human-made hazards. In this context, Structural Health Monitoring (SHM) systems can effectively contribute to the real-time assessment of a building, especially as they allow the detection of structural anomalies that may indicate damage. SHM is the process of performing a damage detection strategy for civil engineering structure and other types of systems, implying the observation of the monitored system over time through periodically-spaced measurements, the extraction of damage-sensitive features from the measurements, and the statistical analysis of these properties to determine the current health state of the system. The effects that meteorological phenomena cause on the dynamics of systems arose great interest in SHM, especially when studying civil structures, which are completely exposed to the external environment. As a matter of fact, phenomena such as rain, snow, ice, temperature variation, humidity, etc., can affect the properties (mass and stiffness) of the monitored system and cause temporary and harmless fluctuations of dynamic features used in diagnostics, increasing the uncertainty in the assessment of the structural health and the probability of making errors. Moreover, the aforementioned phenomena affect not only the structure itself but also the soil on which it is based, greatly complicating the analysis of the relationships between the various quantities. In fact, complications arise in establishing whether and to what extent the variation in dynamic diagnostic features is due to the effect of the environment on the structure itself or on the soil, which will also be subject to changes in mechanical properties. For these rea-sons,SHM of civil structures has spread over last decades and nowadays it is the area that study and analyses the structural health state and its monitoring. Its techniques play an important role in making our structures safe. When studying the health state of structures, a key concept is represented by the state of damage. The structure is defined as "damaged" when it no longer performs in its ideal condition but can still work satisfactorily and safely, it could be defined as a non-optimal situation.

This definition implies that the analysis of the damage state of a structure is based on the comparison between two different states of the system, one of which represent the initial state and a second state in which the potential onset of damage is studied. The study of damage identification in structural and mechanical systems focuses precisely on this problem. In order to be able to study the different states of the structure and therefore a possible evolution of damage, it has to define the characteristics of the structure that allow to understand what state it is in, such, for example, the natural frequencies and modes of the system. Data-driven approaches in SHM are usually used in the case of data coming from permanent or long-term monitoring systems installed on buildings since a lot of samples are available. These kinds of data can be influenced by variations caused by changes in the external environment or by noise, which must be isolated and removed in order to be able to study the actual health state without external effects. In addition, processing errors can lead to a misinterpretation of the path of natural frequencies when mo nitored over time. For example, for each new identification task it is necessary to attribute each identified mode to a previously identified time series, which then distinguishes a specific mode of vibration over time (mode-tracking problem). If the automatic process with which new frequency values are attributed to the histotical series.

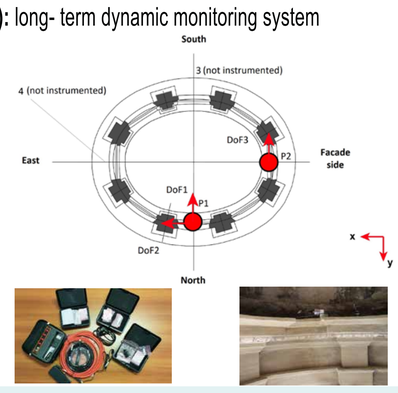
CASE STUDIES

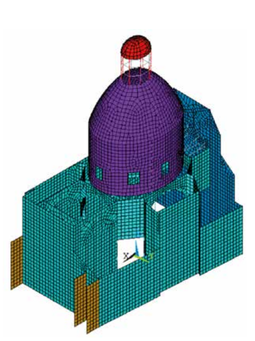
Sanctuary of Vicoforte: permanent dynamic and static monitoring system





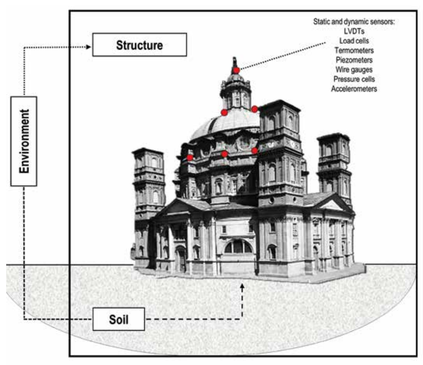
Church of Santa Caterina (Casale Monferrato): long- term dynamic monitoring system





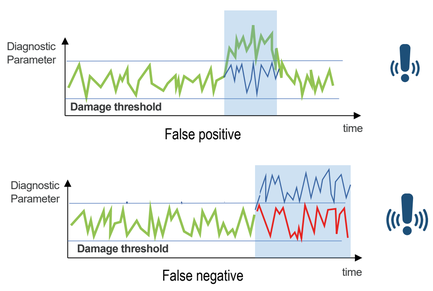
RESEARCH ACTIVITIES

Monitored system with different type of sensors

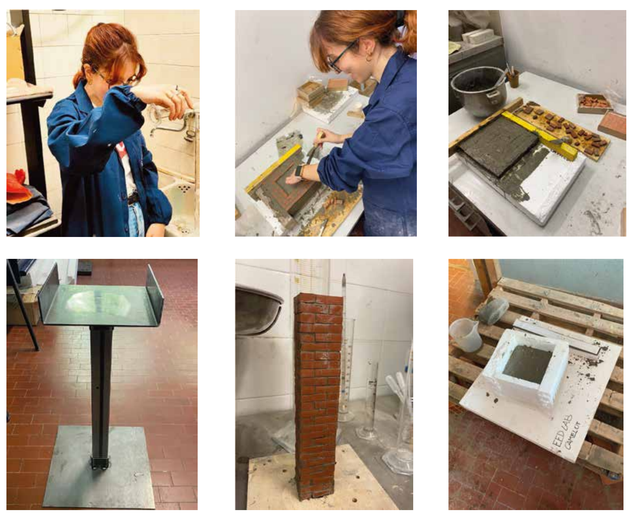


Analysis of structural data acquired in situ by sensors and other data from external environment in order to analyze different scenarios of damage

Useful tool: statistical inference to study the relation between dynamic parameters and external variables in order to avoid wrong interpration of the results.



Experimental test

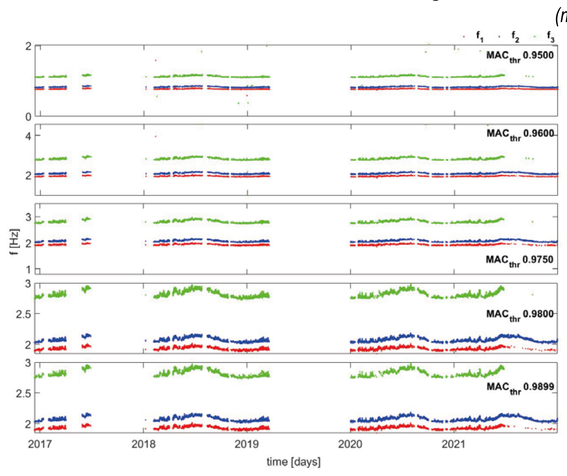


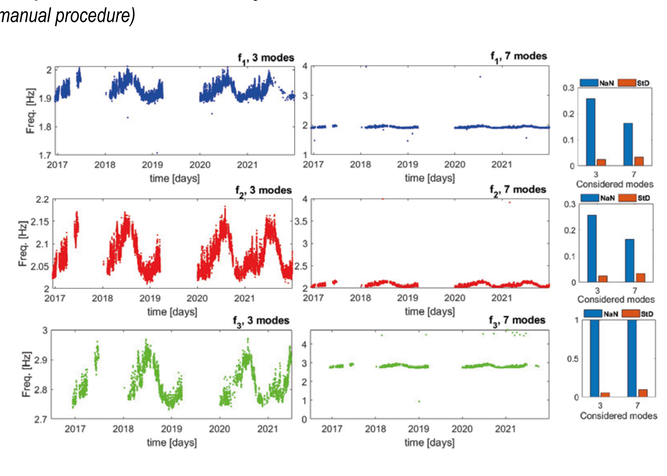
- Experiment for the study of mass variation as a function of water content (for masonry, concrete and steel).
- Experiment for the of stiffness variation as a funciont of temperature (for masonry, concrete and steel).

Why do the natural frequencies change?

Mode tracking of the natural frequencies for the Sanctuary of Vicoforte

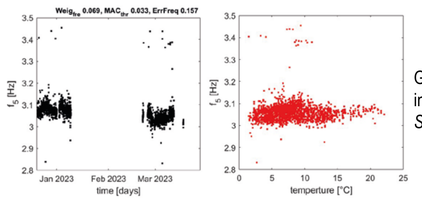
(manual procedure)



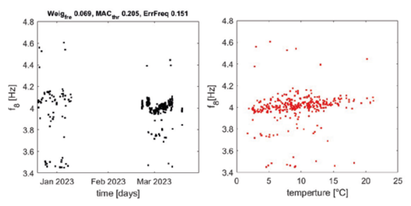


Mode tracking of the natural frequencies for the Church of Santa Caterina

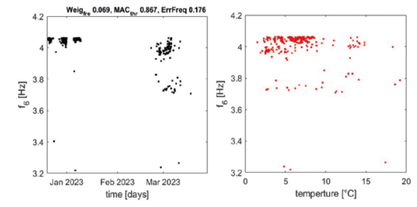
(automatic procedure)



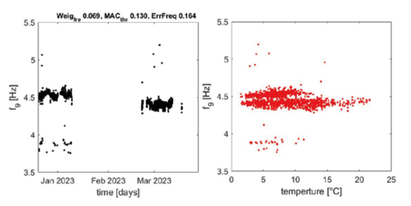
Global transversal mode in y direction
Stable mode



"Torsional" mode
Unstable mode



Local mode of the facade
Unstable mode



Global longitudinal mode in x direction
Stable mode

BRIDGES INSPECTIONS

Bridges located in Piedmont

DISSEMINATION AND TEACHING ACTIVITIES

Conference presentation:
European Workshop of Structural Health Monitoring - Presentation: "Integrated Use of Space-Born Data for SHM of an Ancient Infrastructure";
Fabre Conference - Ponti, viadotti e gallerie esistenti:ricerca,innovazione e applicazioni - Presentation: "Valutazione strutturale di ponti esistenti mediante analisi su scala territoriale";
8th Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering - Presentation:"Analysis of the damage state of a monumental building by considering the variations in soil conditions";
Biennale Tecnologia Politecnico di Torino - R3C- Città resilienti per un futuro sostenibile, Presentation: "Il ruolo dei dati satellitari nel monitoraggio del patrimonio del costruito".
Supervision MsC thesis:
"Analisi e monitoraggio di ponti esistenti" - (Student S. Pochettino)
"Classificazione e tracciamento automatico dei modi strutturali nel monitoraggio dinamico a lungo termine: validazione su una chiesa barocca" - (Student R. Ravizza)
"Identificazione del Danno in Opere Strutturali tramite FEM: verso il Digital Twin" - (Student M.Carere)
"Applicazione dei dati satellitari del programma Copernicus per indagare l'effetto del suolo sulla dinamica delle strutture" - (Student M.Congedo)
"Structural assessment of existing bridges by means of territorial scale analyses" - (Student L.M. Di Valentino)
"Analisi statistica per la valutazione del rischio di ponti esistenti" - (Student T. Campagna)
Courses tutor:
Ingegneria Sismica (Prof. R. Ceravolo) A.Y. 2021/2022;
Earthquake Engineering (Prof. R. Ceravolo) A.Y. 2022/2023;
Earthquake Engineering (Prof. R. Ceravolo) A.Y. 2023/2024.

PUBLICATIONS

Scientific journals:
Coccimiglio, S., Coletta, G., Lenticchia, E. et al. Combining satellite geophysical data with continuous on-site measurements for monitoring the dynamic parameters of civil structures. Scientific Reports (Nature), 12, 2275 (2022). https://doi.org/10.1038/s41598-022-06284-7.
Coccimiglio, S., Miraglia, G. Coletta, G., Epicoco, R., Ceravolo, R. Balanced definition of thresholds for mode-tracking in a long-term seismic monitoring system, (2023). Manuscript submitted for publication on Geoscience

Conferences:
Coccimiglio,S.,Miraglia,G. and Ceravolo, R. Adaptive hypermaramters selection for Modal Tracking algorithm in Structural Health Monitoring of masonry monumental structures, submitted for 18th International Brick and Block Masonry Conference, University of Birmingham, 2024.
Coccimiglio, S., Miraglia, G., Coletta,G., Ceravolo, R. Statistical inference of the environment-dependent dynamics of long-term monitored built heritage,accepted for World Conference of Earthquake Engineering, Milan 2024.
Coccimiglio, S., Scussolini, L., Matteini, I., Ceravolo, R., Ferro, G.A. Interferometric satellite data for the Structural Health Monitoring of instrastructures, accepted for Ponti, viadotti e gallerie esistenti: ricerca, innovazione e applicazioni, Genova , 2024.
Coccimiglio, S., Coletta, G., Lenticchia, E., Miraglia, G., Ceravolo, R. (2022). Integrated Use of Space-Born Data for SHM of an Ancient Infrastructure. In: Rizzo, P., Milazzo, A. (eds) European Workshop on Structural Health Monitoring. EWSHM 2022. Lecture Notes in Civil Engineering, vol 254. Springer, Cham. https://doi.org/10.1007/978-3-031-07258-1_38;
Coccimiglio, S.,Di Valentino, L.M., Lenticchia,E., Oliva, V., Scussolini,L., Falliano, D., Montagnoli, F., Alvi, M.R., Barla, M., Ceravolo, R., Corrado, M., Ferro, G.A., Insana, A., Invernizzi,S., Restuccia,L. Structural assessment of existing bridges by using territorial scale analysis: some observations on the application of the Italian guidelines. PONTI, VIADOTTI, E GALLERIE ESISTENTI RICERCA, INNOVAZIONE E APPLICAZIONI, 2-4 Febbraio 2022, Lucca;
Coccimiglio, S., Coletta G., Dabdoub, M., Miraglia, G.,Lenticchia, E., Ceravolo, R. Use of Copernicus satellite data to investigate the soil-structure interaction and its contribution to the dynamics of a monitored monumental building. In Proceedings of 1st European Conference of the European Association on Quality Control of Bridges and Structures.Padova, Italy, August 29-September 1, 2021;
Lenticchia, E., Miraglia, G., **Coccimiglio, S**., Ceravolo, R. Analysis of the damage state of a monumental building by considering the variations in soil conditions. In Proceedings of 8th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering. Athens, Greece, June 27-30, 2021.

PARTECIPATION IN PROJECT

CAMELOT - struCturAl ModEL cOrroboration Toolbox
Proof of Concept (PoC) **Instrument** Compagnia di San Paolo per per lo sviluppo di prototipi di ricerca o dimostratori
CAMELOT - struCturAl ModEL cOrroboration Toolbox
Proof of Concept (PoC) **Transition** Compagnia di San Paolo per per lo sviluppo di prototipi di ricerca o dimostratori

Fabre - Consorzio nazionale di ricerca per la valutazione e il monitoraggio di ponti,viadotti e altre strutture
• Assessment of A10 e A32 highways for Gavio company;
• Classification of ANAS bridges according to the new Lines guide for risk classification and management, safety assessment and monitoring of existing bridges for the Valle d'Aosta, Piedmont and Sicily.
• Classification of ANAS bridges according to the new Lines guide for risk classification and management, safety assessment and monitoring of existing bridges for CMTO (Città Metropolitana di Torino)

ReLUIS Rete dei Laboratori Universitari di Ingegneria Sismica
"Dipartimento di Protezione Civile - ReLUIS 2019-2021 - WP6 - Monitoraggio Dati Satellitari". Task 6 - Monitoraggio dati satellitari
Focus: integration of satellite data with recorded in situ from systems installed on monumental buildings and infrastructures and application of interferometric data of the city of Rome provided by the CNR.

ATTENDED CLASSES HOURS

Hard skills:
115/100 hours

Soft skills:
167/40 hours

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