A.D. 1308
unipg
DEPARTMENT OF CIVIL
AND ENVIRONMENTAL
ENGINEERING

FABRE

SOFTWARE IMPLEMENTATION OF ADVANCED SHM ALGORITHMS

Cergy-Pontoise 2° June 2023

HAROS

UNIVERSITÉ
de Cergy-Pontoise

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OUTLINE

- Introduction and motivation
- Data driven and model-based SHM
- Software implementation: MOSS and P3P
- Conclusions

INTRODUCTION AND MOTIVATION

Local defects cause global failures!

(a) moderate

(b) severe

a

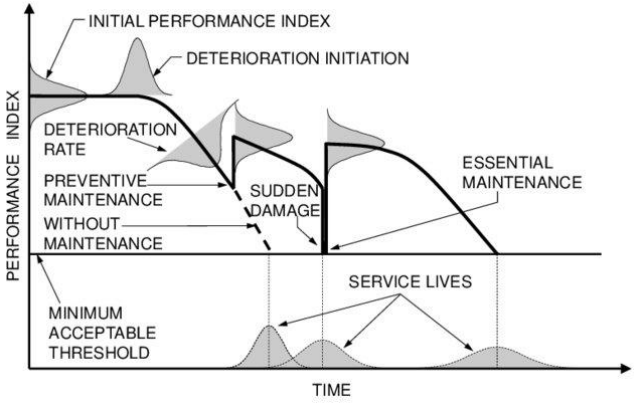
b

c

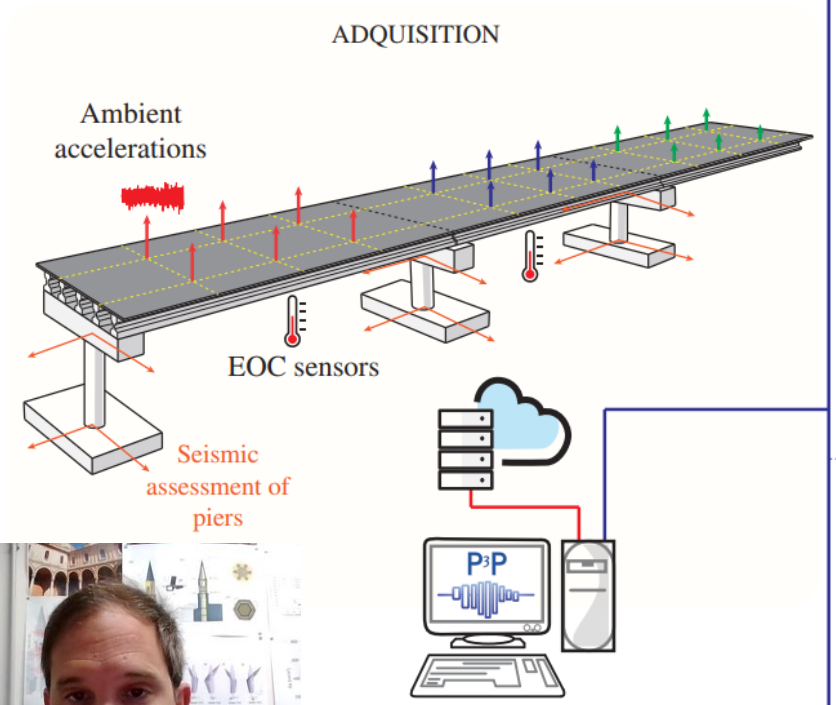
d

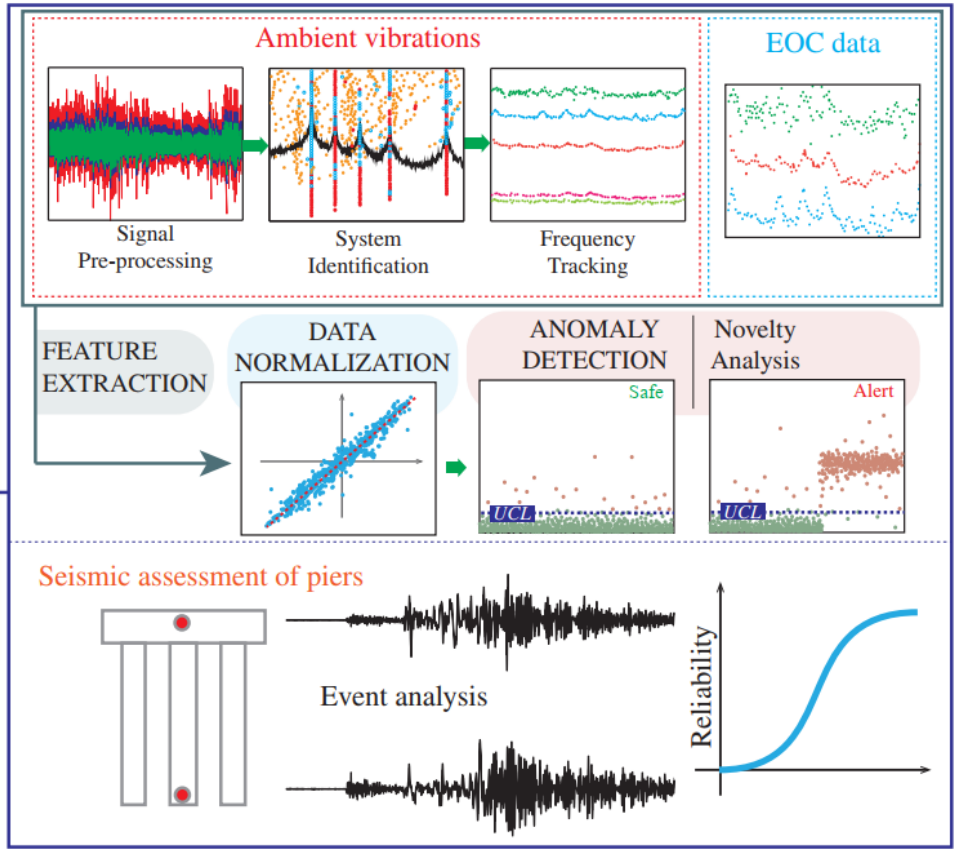
e

f



DATA-DRIVEN SHM

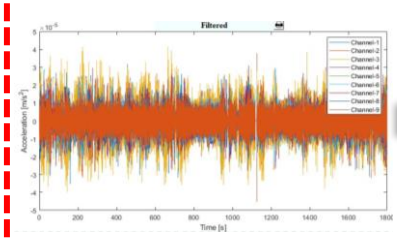


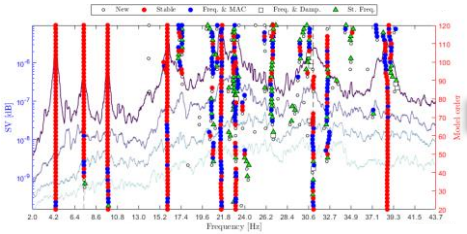


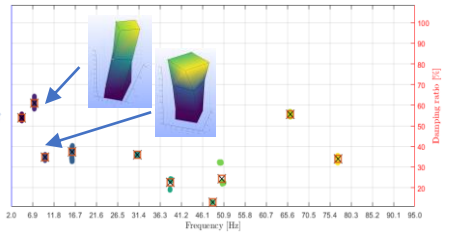
DATA-DRIVEN SHM

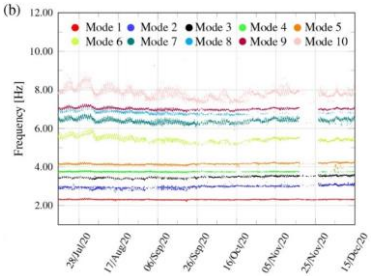
Dynamic data

Frequency tracking

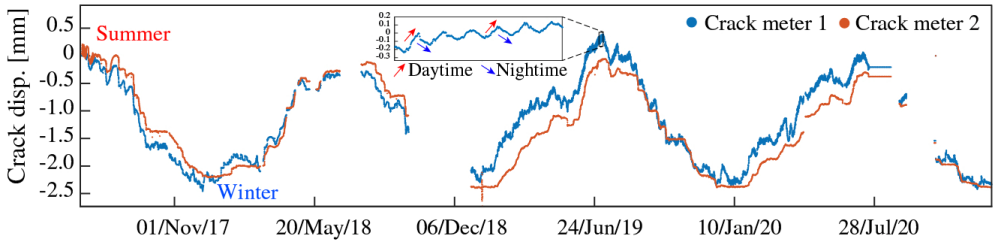




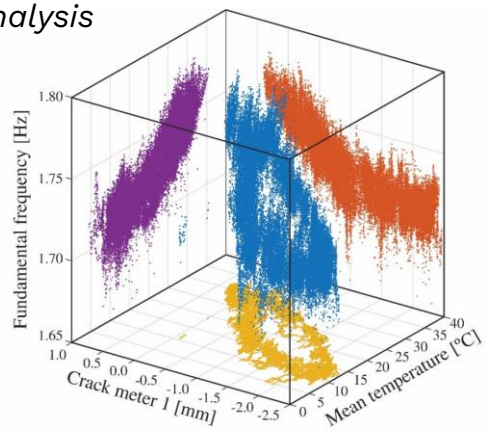




Environmental/Static data

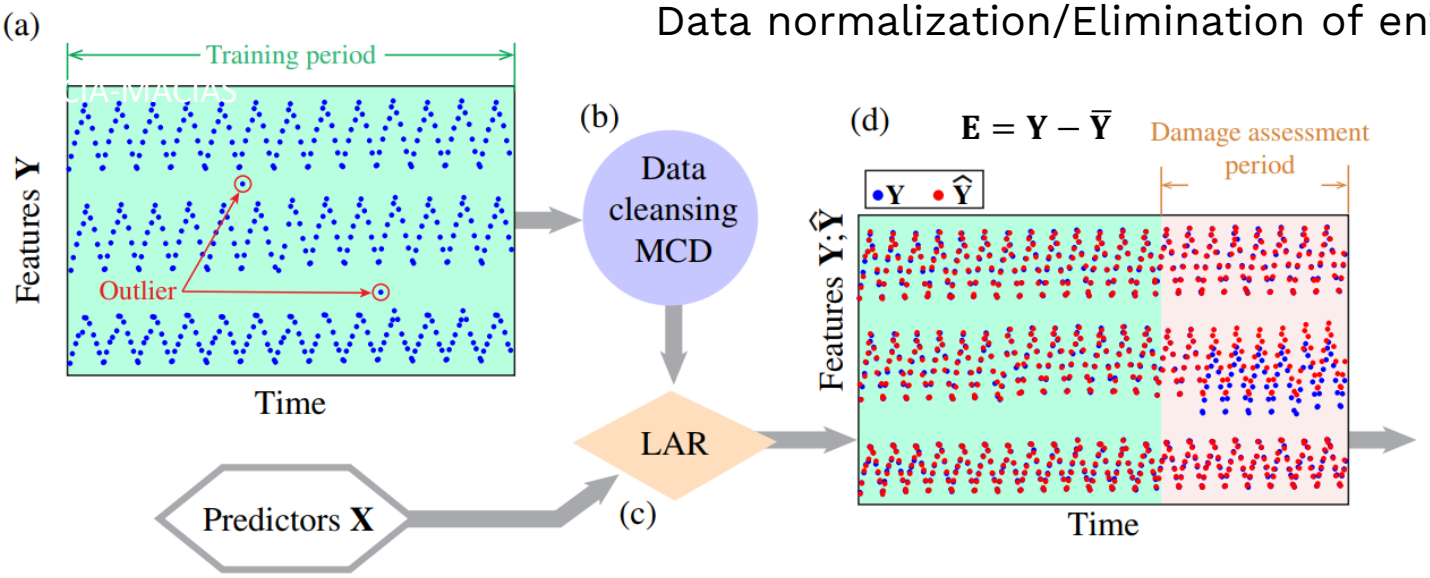


Correlation analysis

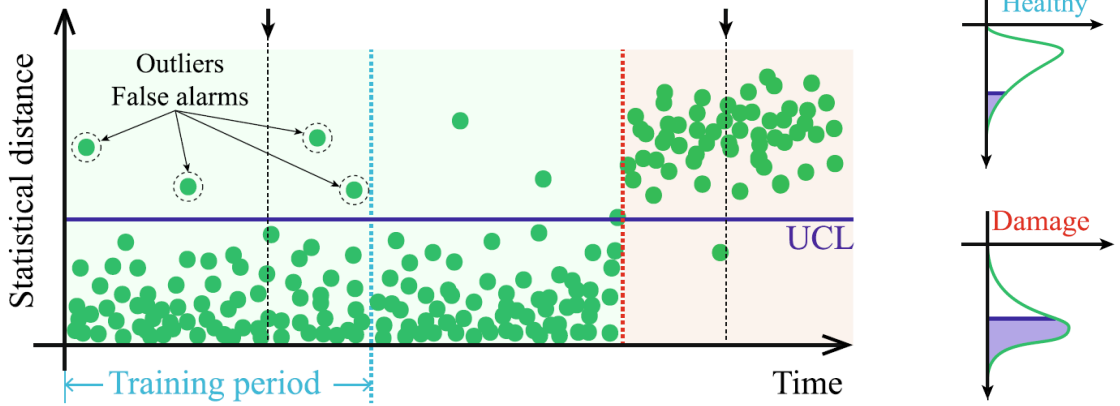


DATA-DRIVEN SHM

Data normalization/Elimination of env. effects



Novelty analysis for damage detection



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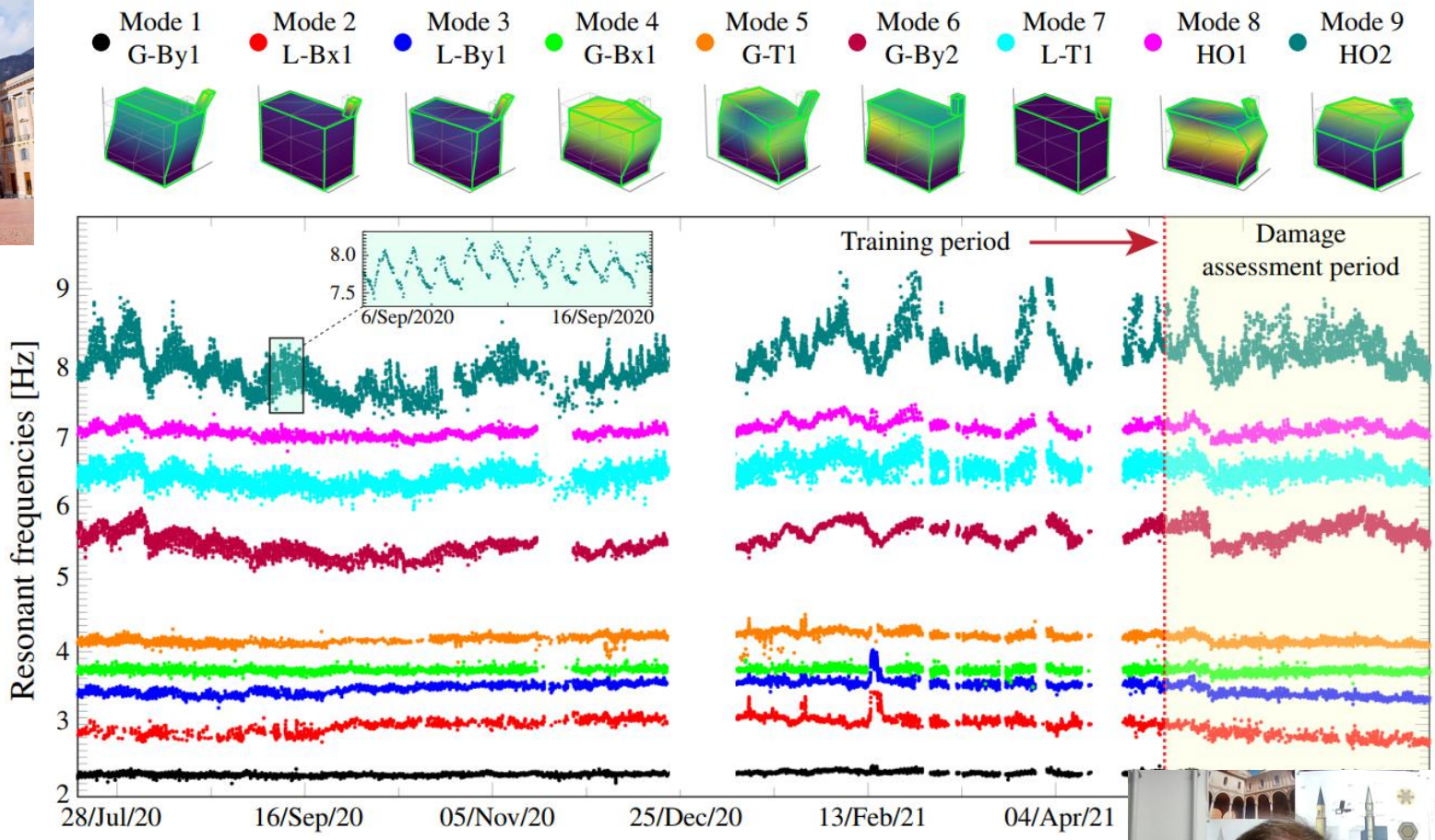
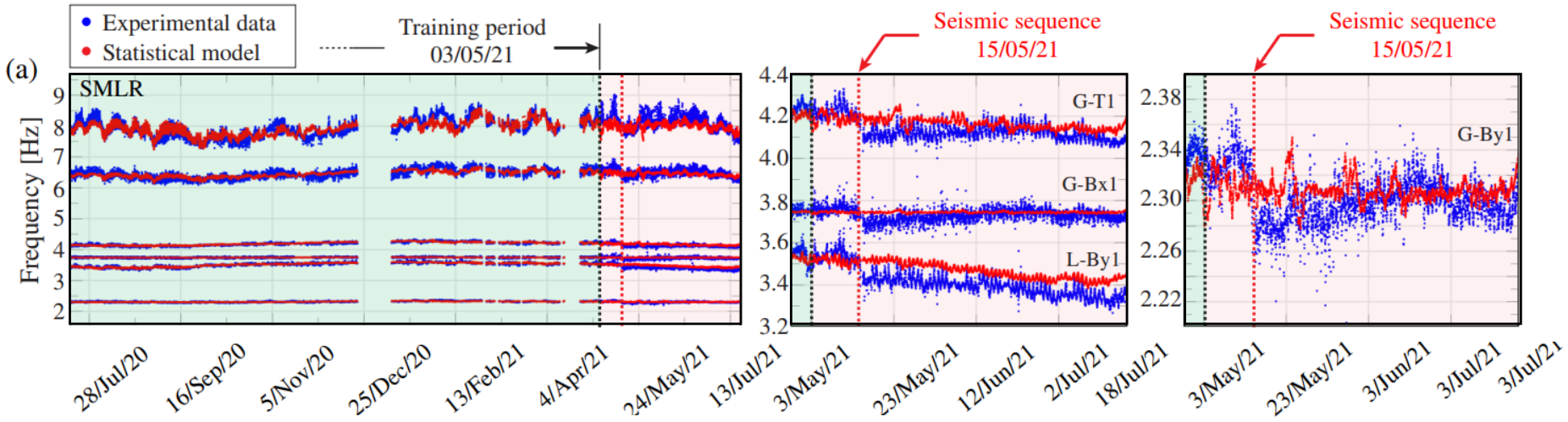
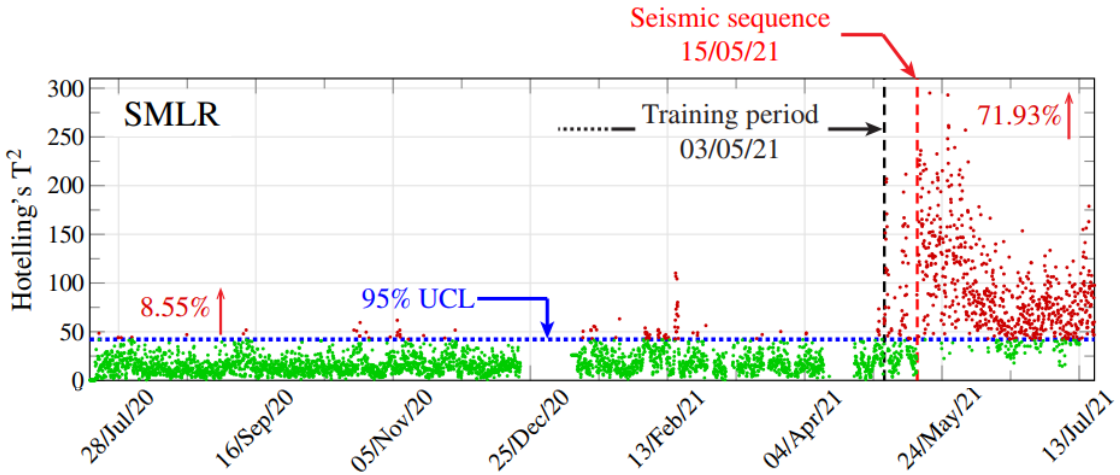


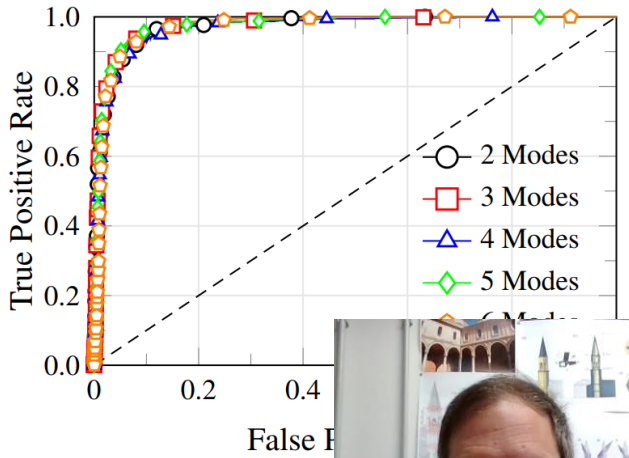
García-Macías, E., & Ubertini, F. (2020). MOVA/MOSS: Two integrated software solutions for comprehensive Structural Health Monitoring of structures. Mechanical Systems and Signal Processing, 143, 106830.

García-Macías, E., & Ubertini, F. (2022). Least Angle Regression for early-stage identification of earthquake-induced damage in a monumental masonry palac
Structures, 259, 114119.

DATA-DRIVEN SHM







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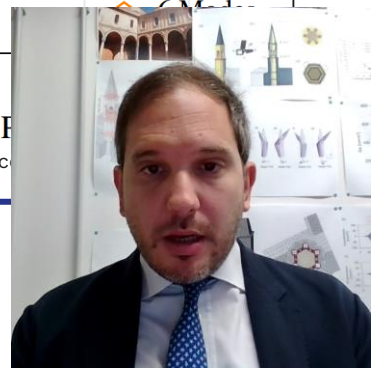
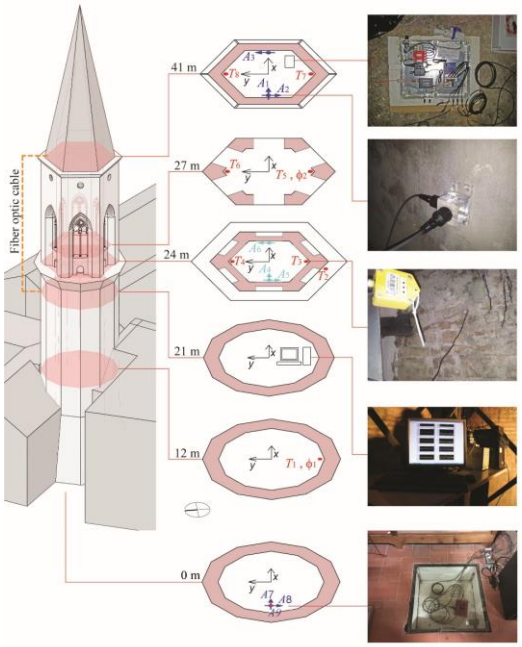
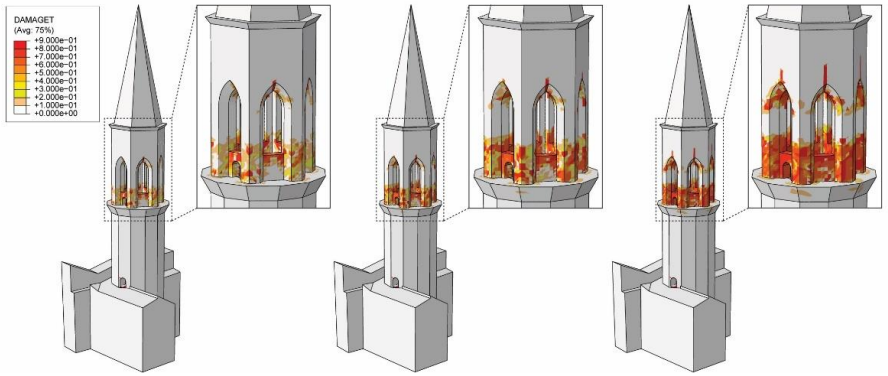
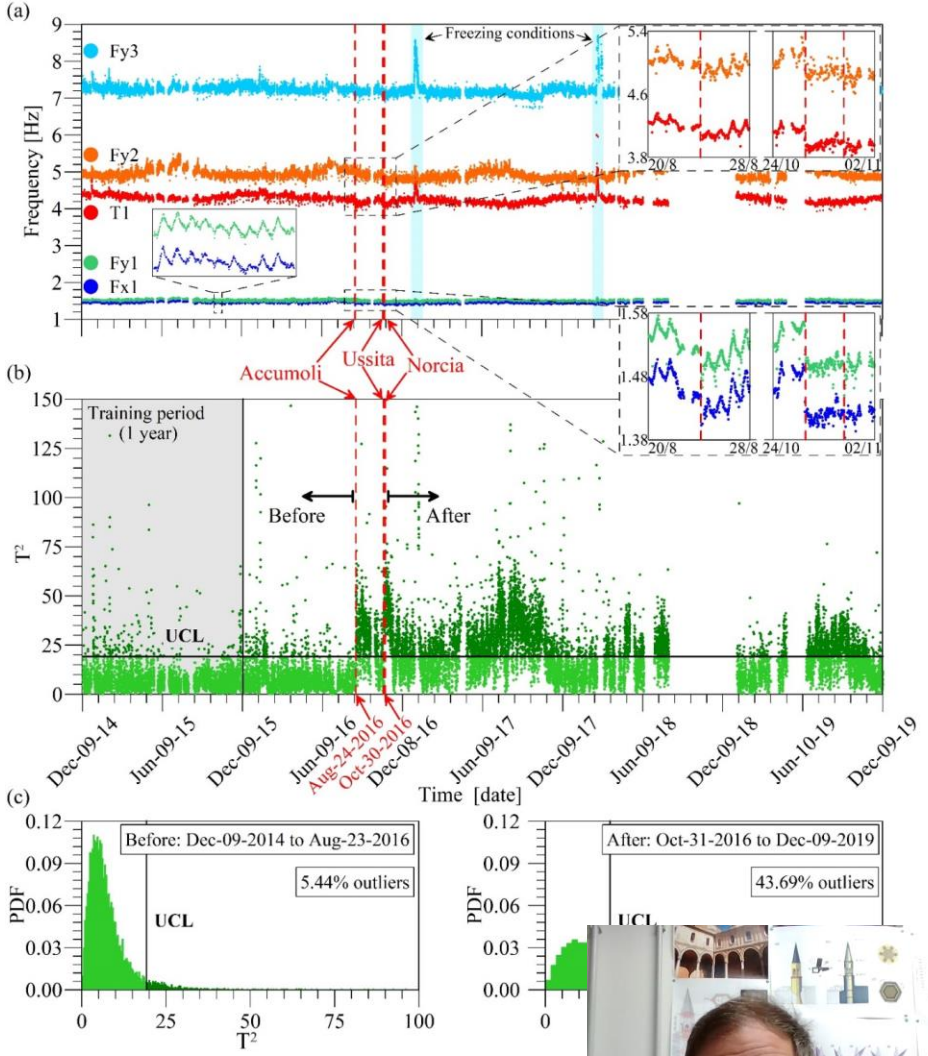


MODEL-BASED SHM







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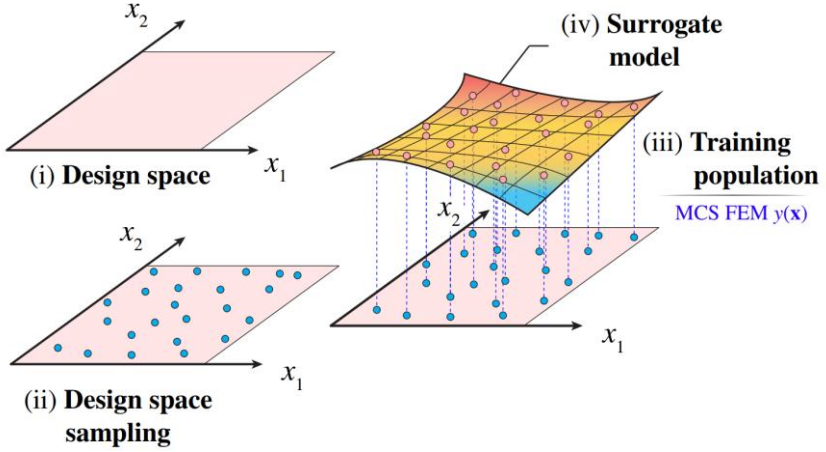
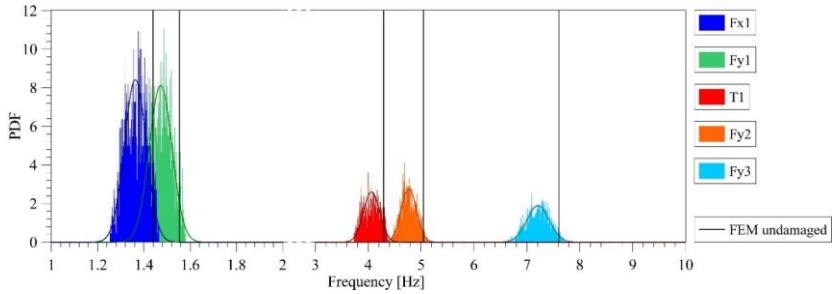
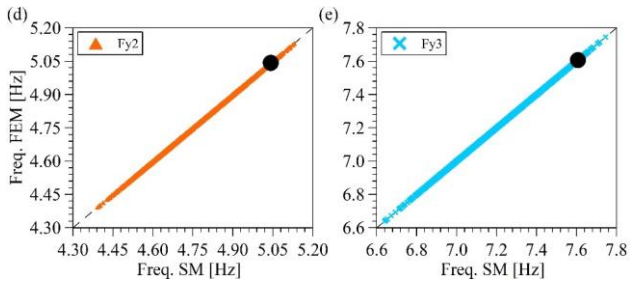
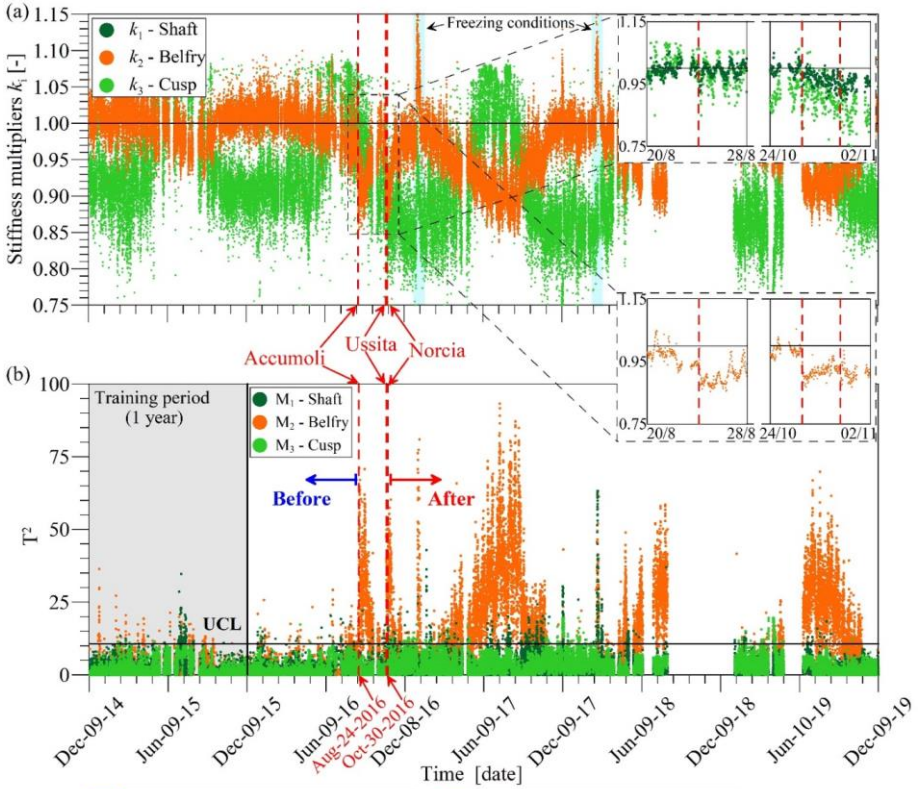
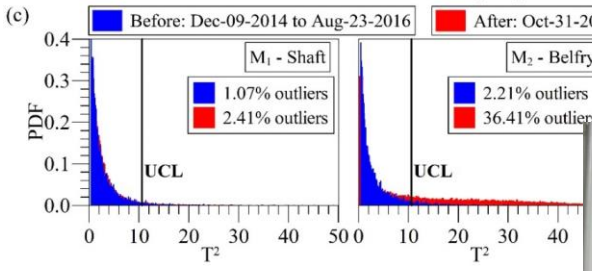










MODEL-BASED SHM

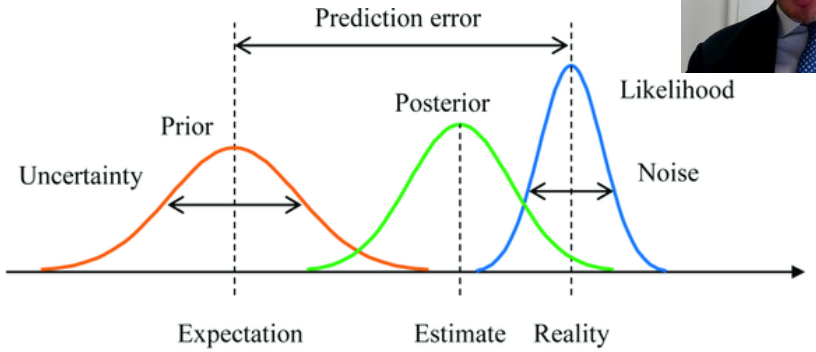
Likelihood function

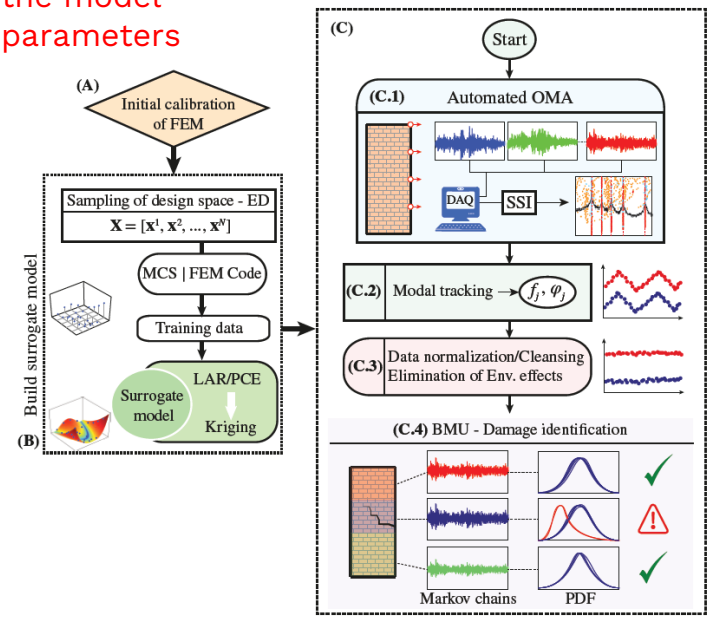
Prior distribution of the model parameters

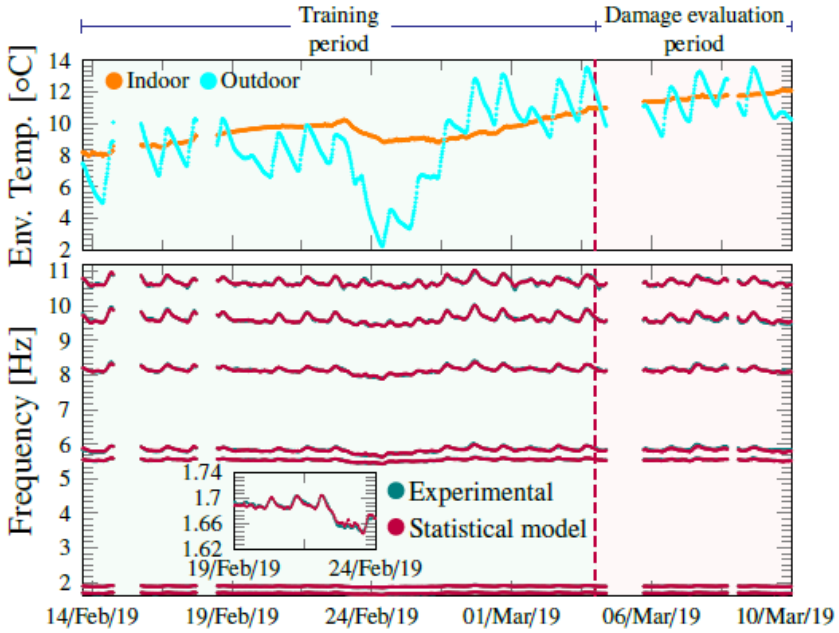
$$p\left(\mathbf{x}(t)|\,\mathbf{d}(t),\widehat{\mathcal{M}}\right)=\frac{p\left(\mathbf{d}(t)|\,\mathbf{x}(t),\widehat{\mathcal{M}}\right)p\left(\mathbf{x}(t)|\,\widehat{\mathcal{M}}\right)}{p\left(\mathbf{d}(t)\,(t)|\,\widehat{\mathcal{M}}\right)}$$

Posterior distribution of the model parameters

Model evidence

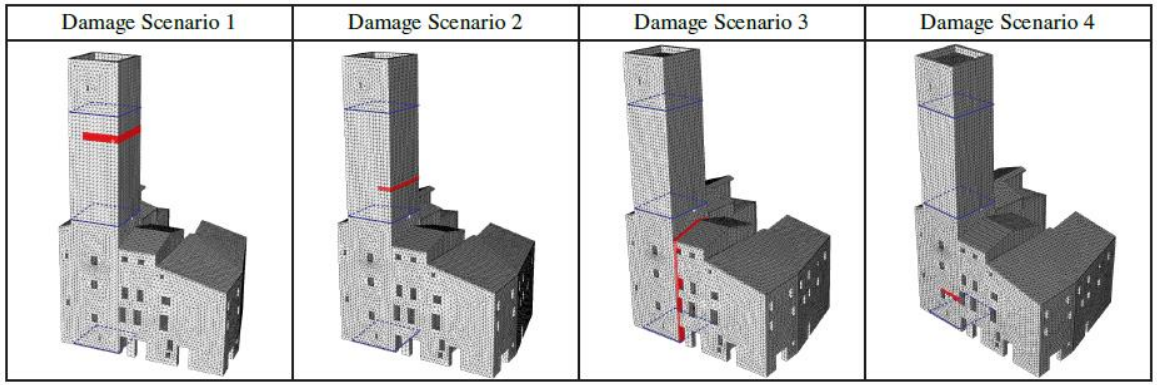


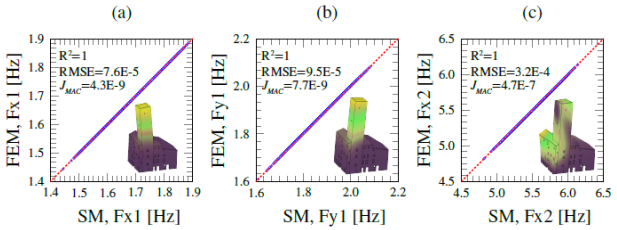




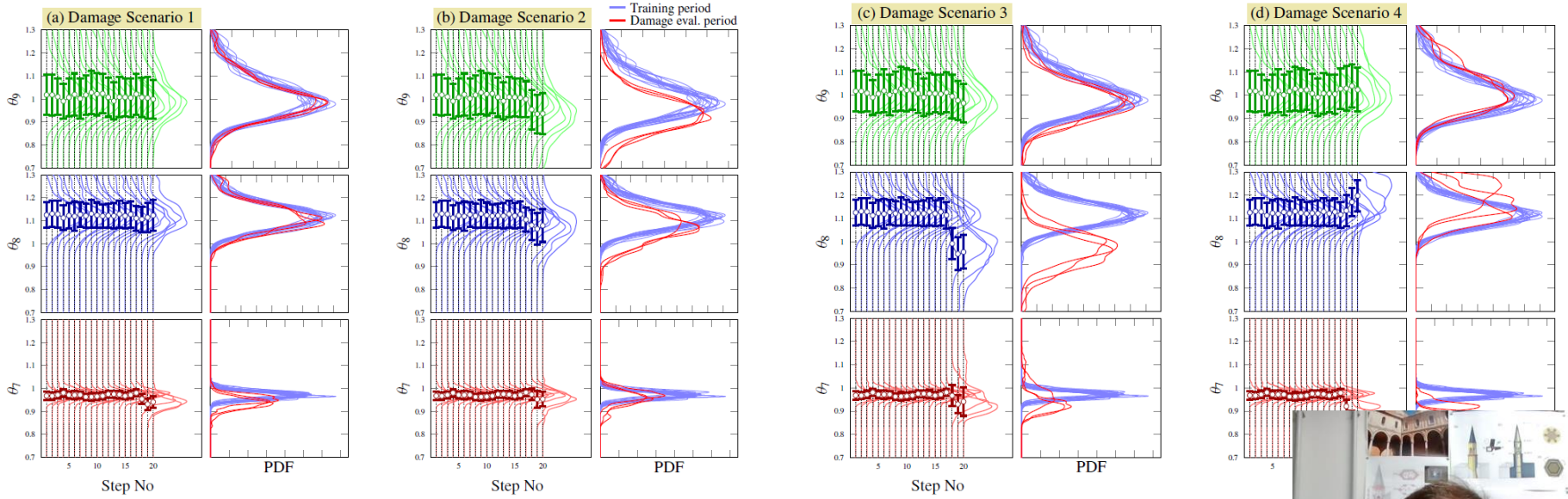
García-Macías & Ubertini, F. (2022). Real-time Bayesian damage identification enabled by sparse PCE-Kriging meta-modelling for continuous SHM of large-scale civil engineering structures. Submitted to Journal of Building Engineering, Under review.

MODEL-BASED SHM





Case scenario	Frequency decays [%]						
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7
Damage Scenario 1	-0.01	-0.02	-0.05	-0.05	-0.02	-0.12	-0.02
Damage Scenario 2	-0.49	-0.58	-1.00	-1.51	-1.55	-3.29	-0.35
Damage Scenario 3	-1.62	-1.70	-1.20	-2.69	-2.70	-3.81	-0.27
Damage Scenario 4	-6.24	-3.36	-1.95	-1.12	-9.11	-1.30	-0.85



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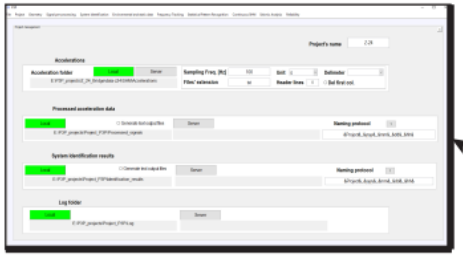
PHYSICS-ENHANCED AI: SHM

Sparse MLR for earthquake-induced damage detection

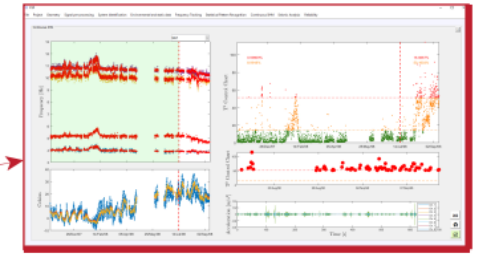
https://www.youtube.com/watch?v=YtRe2nFbW20
http://www.heracles-project.eu/project-test-beds/test-bed-4-palazzo-dei-consoli-gubbio-it

SOFTWARE IMPLEMENTATION: P3P

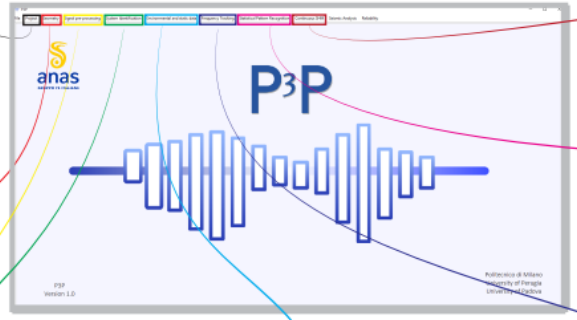
Project configuration



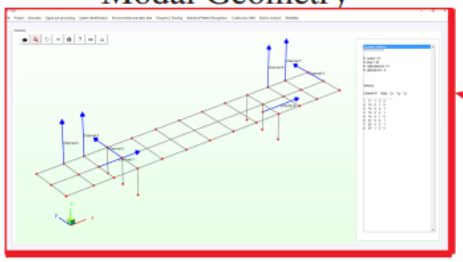
Continuous SHM



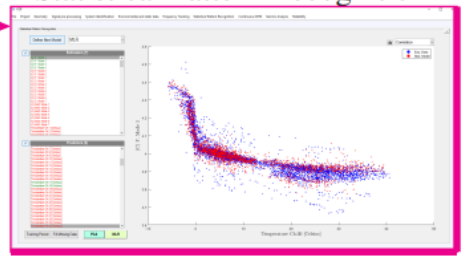
Main GUI



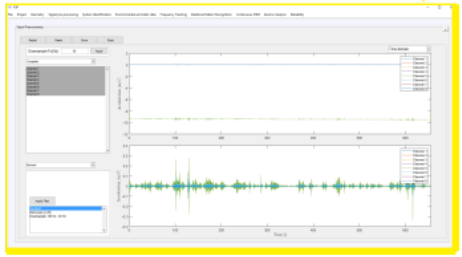
Modal Geometry



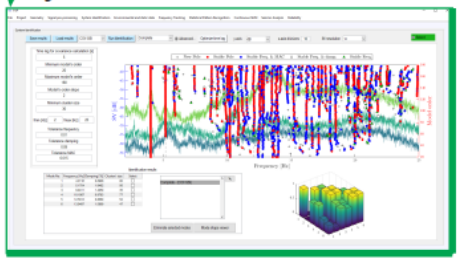
Statistical Pattern Recognition



Signal pre-processing

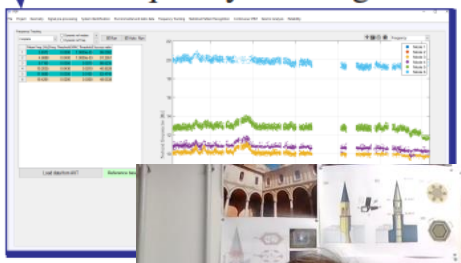


System Identification - OMA



Static/Environmental data

Frequency tracking



SOFTWARE IMPLEMENTATION: P3P

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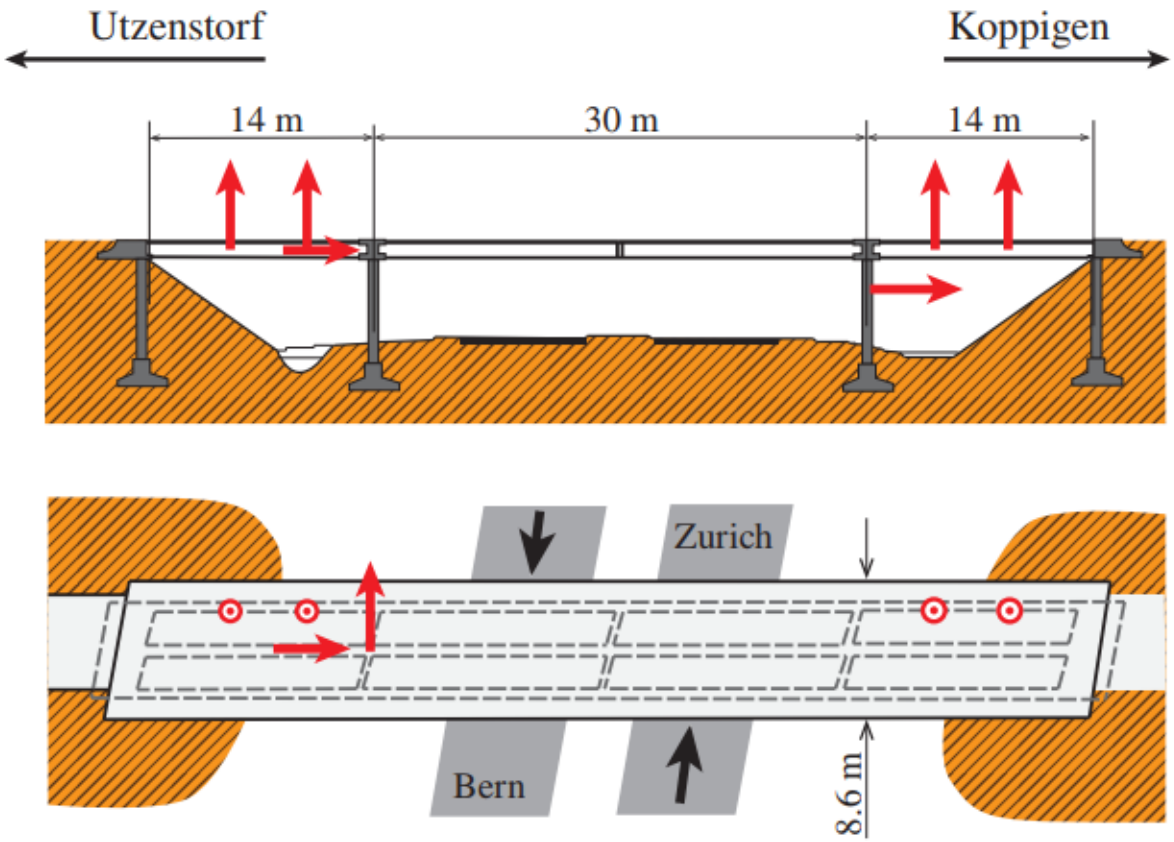
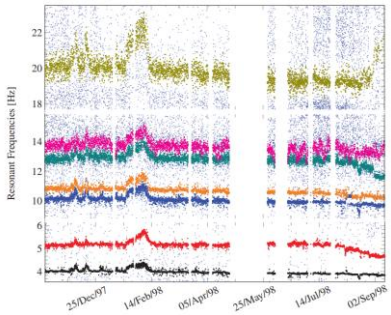
Example application to Z24 Bridge

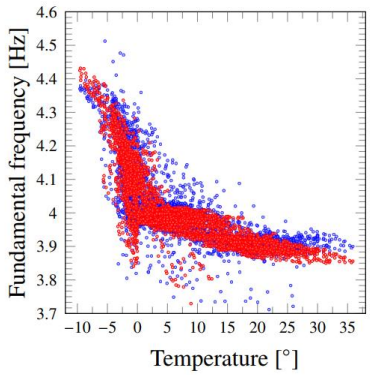


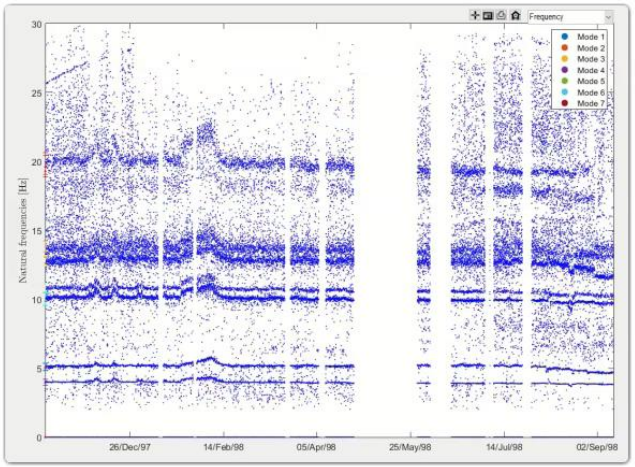
Date (1998)	Scenario
4 August	Undamaged condition
9 August	Installation of pier settlement system
10 August	Lowering of pier, 20 mm
12 August	Lowering of pier, 40 mm
17 August	Lowering of pier, 80 mm
18 August	Lowering of pier, 95 mm
19 August	Lifting of pier, tilt of foundation
20 August	New reference condition
25 August	Spalling of concrete at soffit, 12 m^2
26 August	Spalling of concrete at soffit, 24 m^2
27 August	Landslide of 1 m at abutment
31 August	Failure of concrete hinge
2 September	Failure of 2 anchor heads
3 September	Fail
7 September	Rup
8 September	Rup
9 September	Rup

SOFTWARE IMPLEMENTATION: P3P

Example application to Z24 Bridge







SOFTWARE IMPLEMENTATION: P3P

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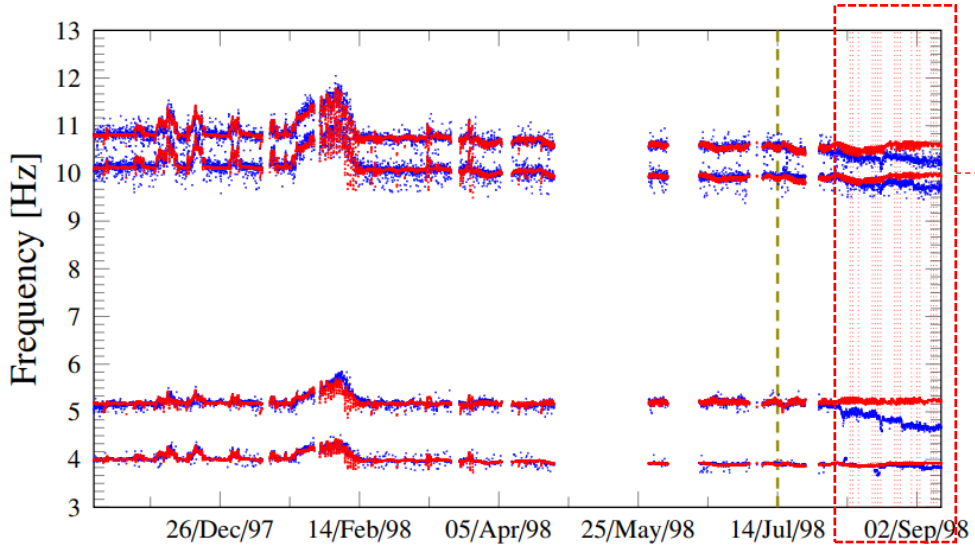

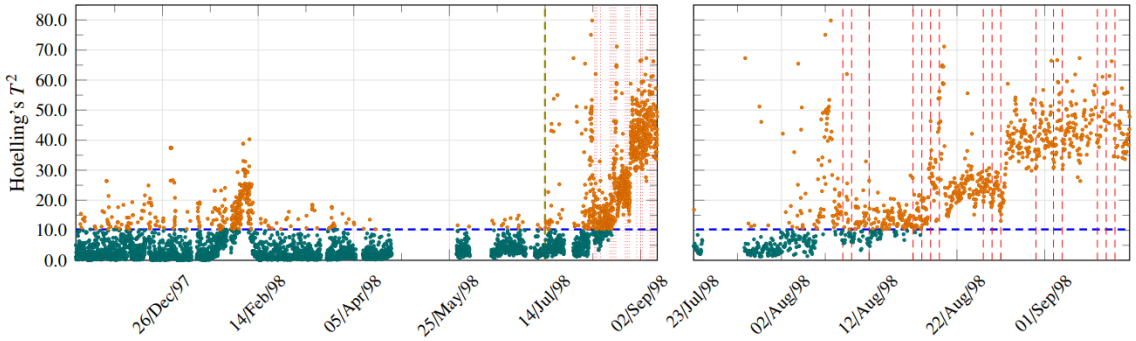

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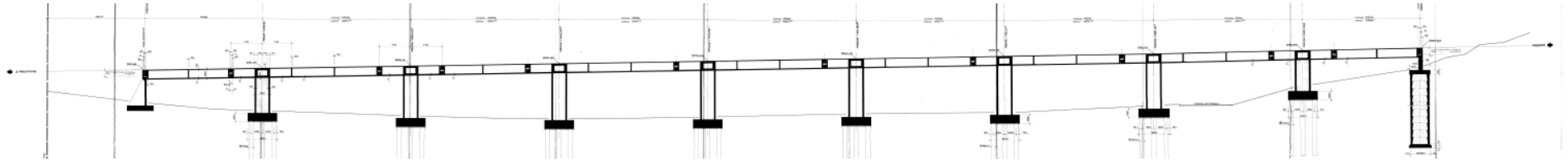
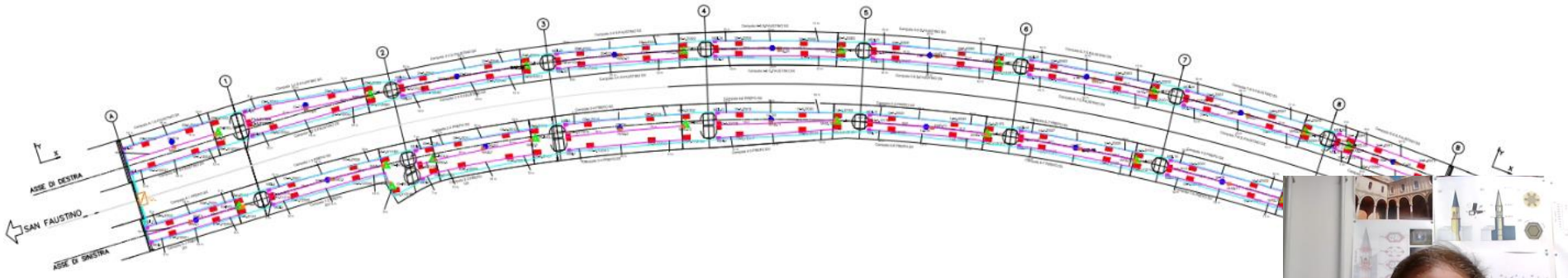
26 August	Spalling of concrete at soffit, 24 m^2
27 August	Landslide of 1 m at abutment
31 August	Failure of concrete hinge
2 September	Failure of 2 anchor heads
3 September	Failure of 4 anchor heads
7 September	Rupture of 2 out of 16 tendons
8 September	Rupture of 4 out of 16 tendons
9 September	Rupture of 6 out of 16 tendons

SOFTWARE IMPLEMENTATION: P3P

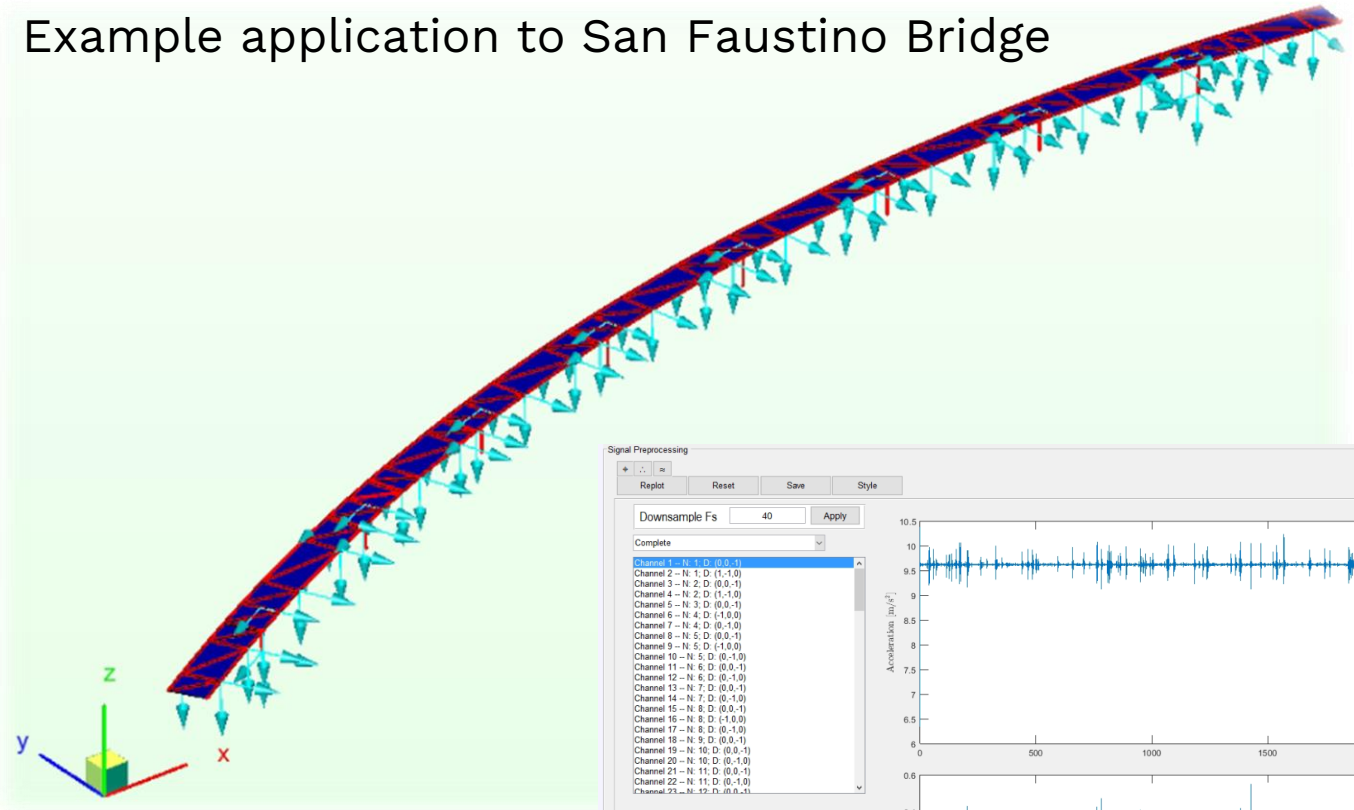
Example application to San Faustino Bridge

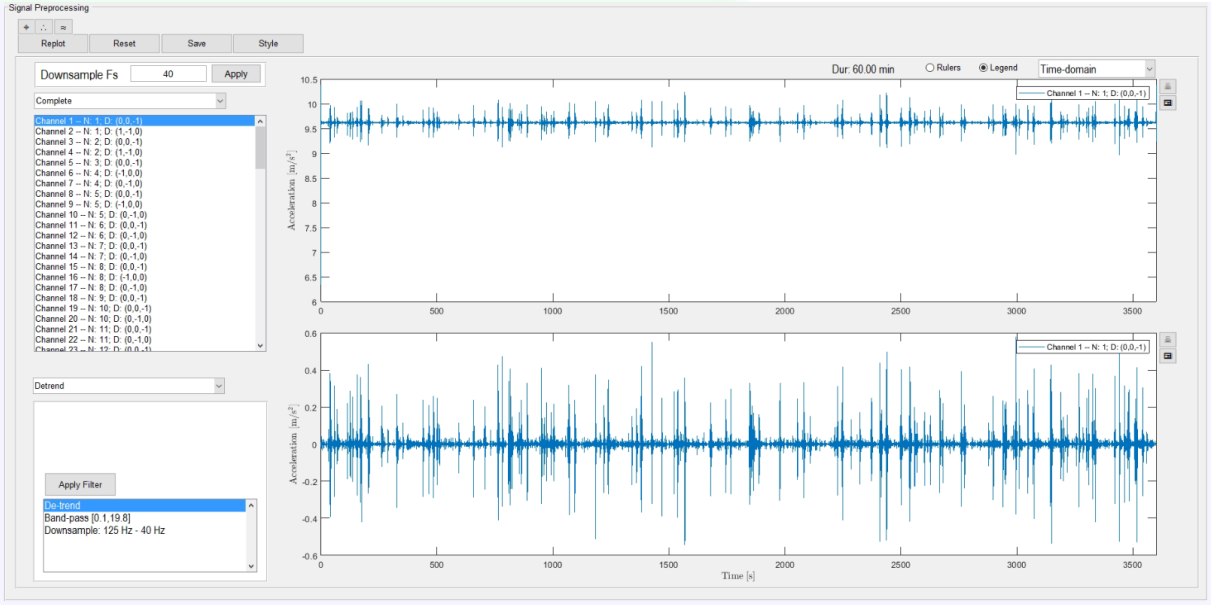




SOFTWARE IMPLEMENTATION: P3P

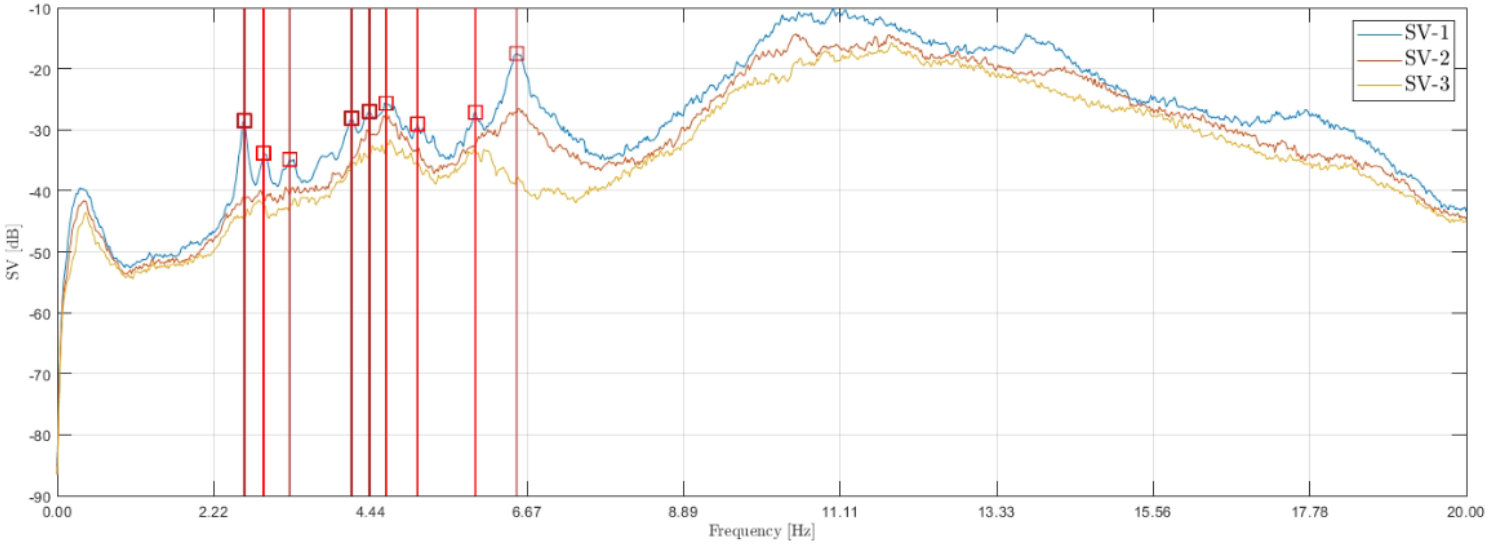
Example application to San Faustino Bridge

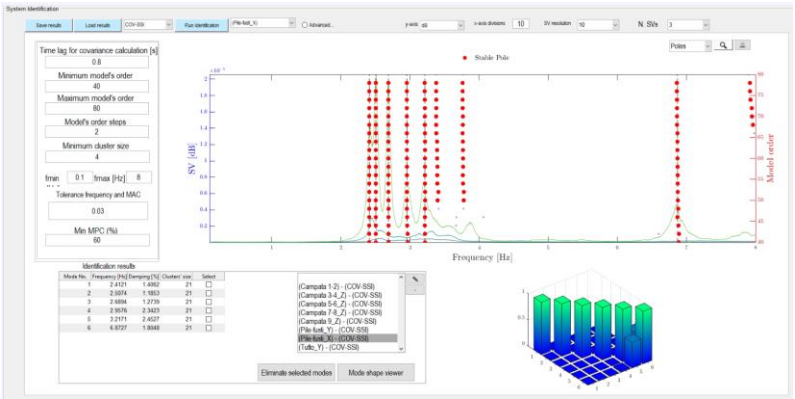




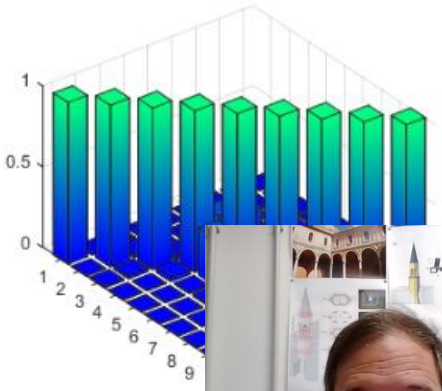
SOFTWARE IMPLEMENTATION: P3P

Example application to San Faustino Bridge





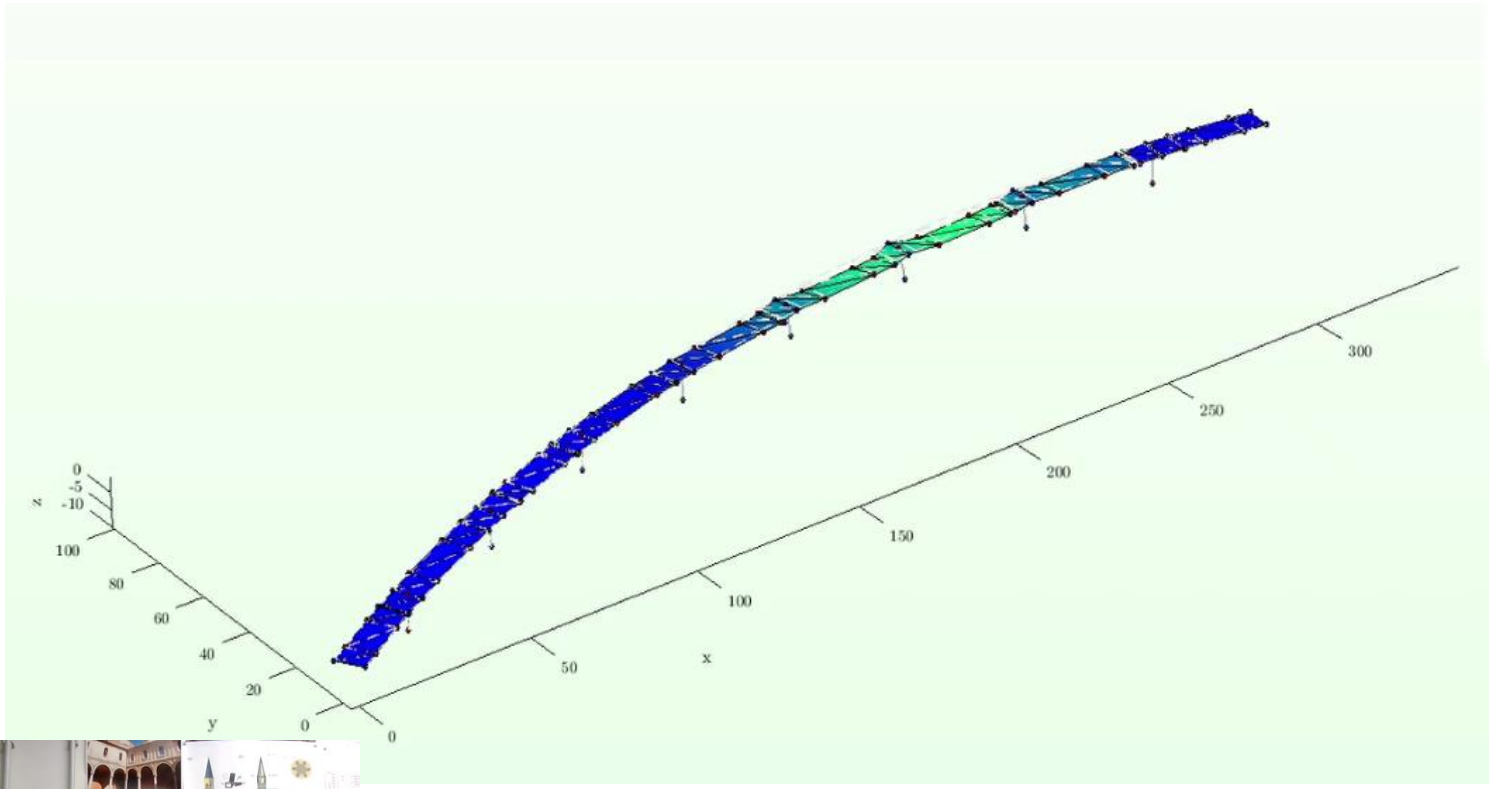
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

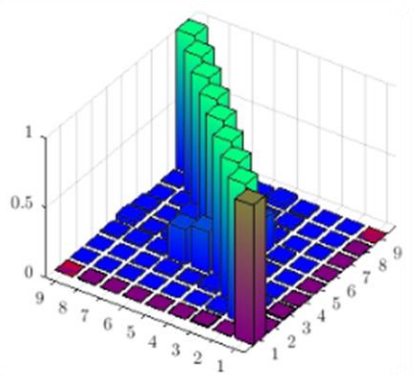


SOFTWARE IMPLEMENTATION: P3P

Mode 1

Example application to San Faustino Bridge



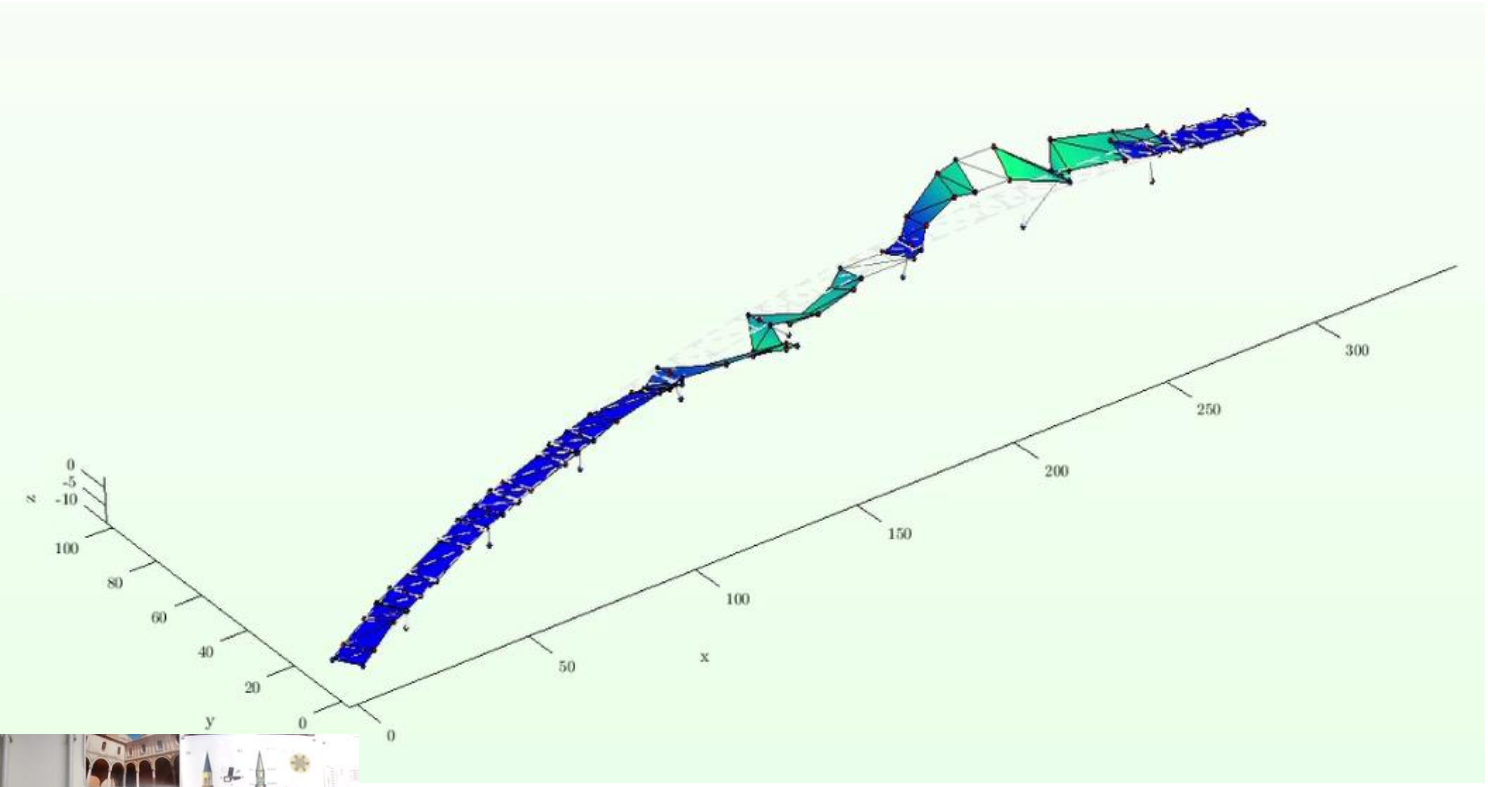


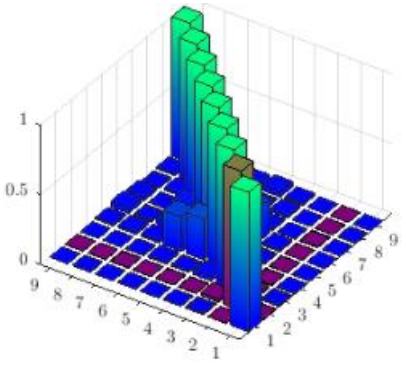
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Mode 2

Example application to San Faustino Bridge



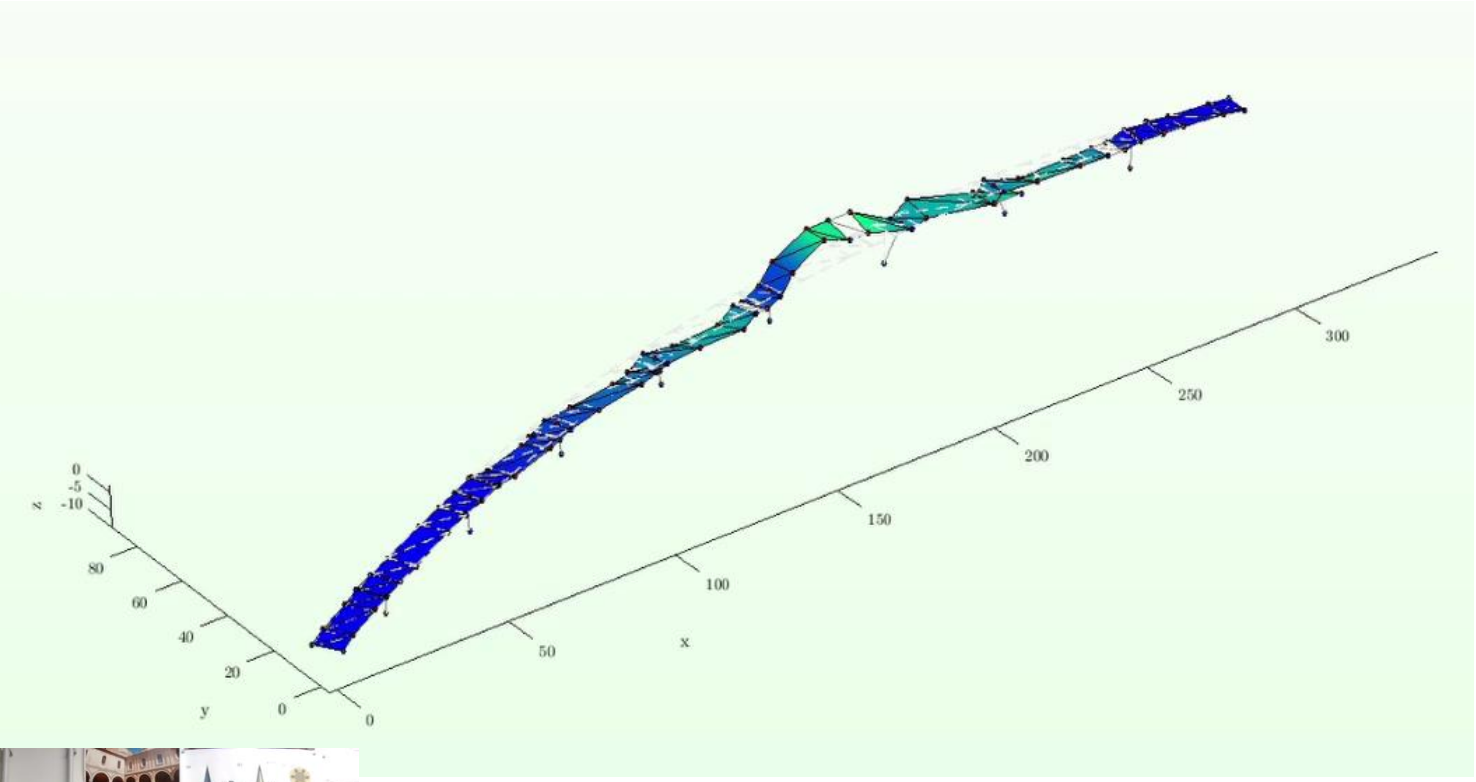


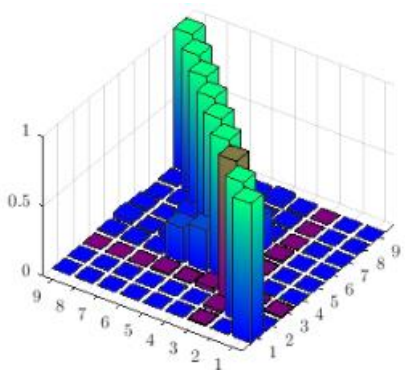
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Mode 3

Example application to San Faustino Bridge



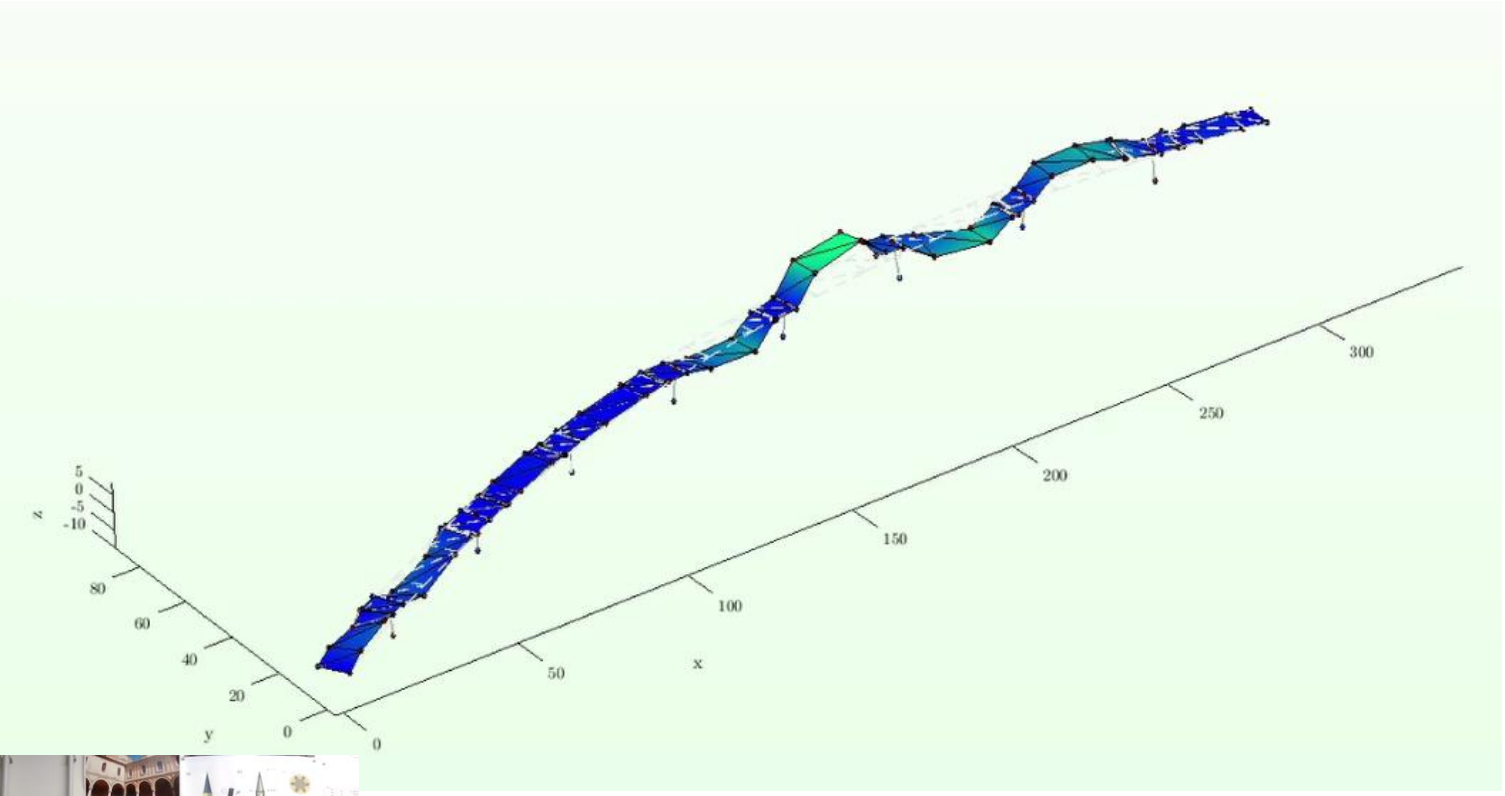


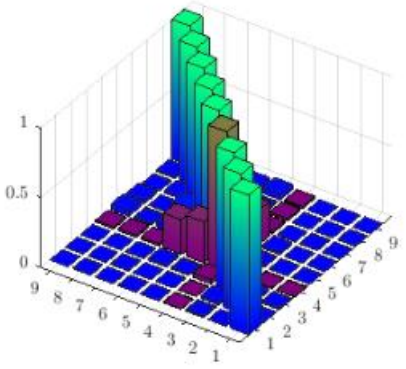
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Mode 4

Example application to San Faustino Bridge



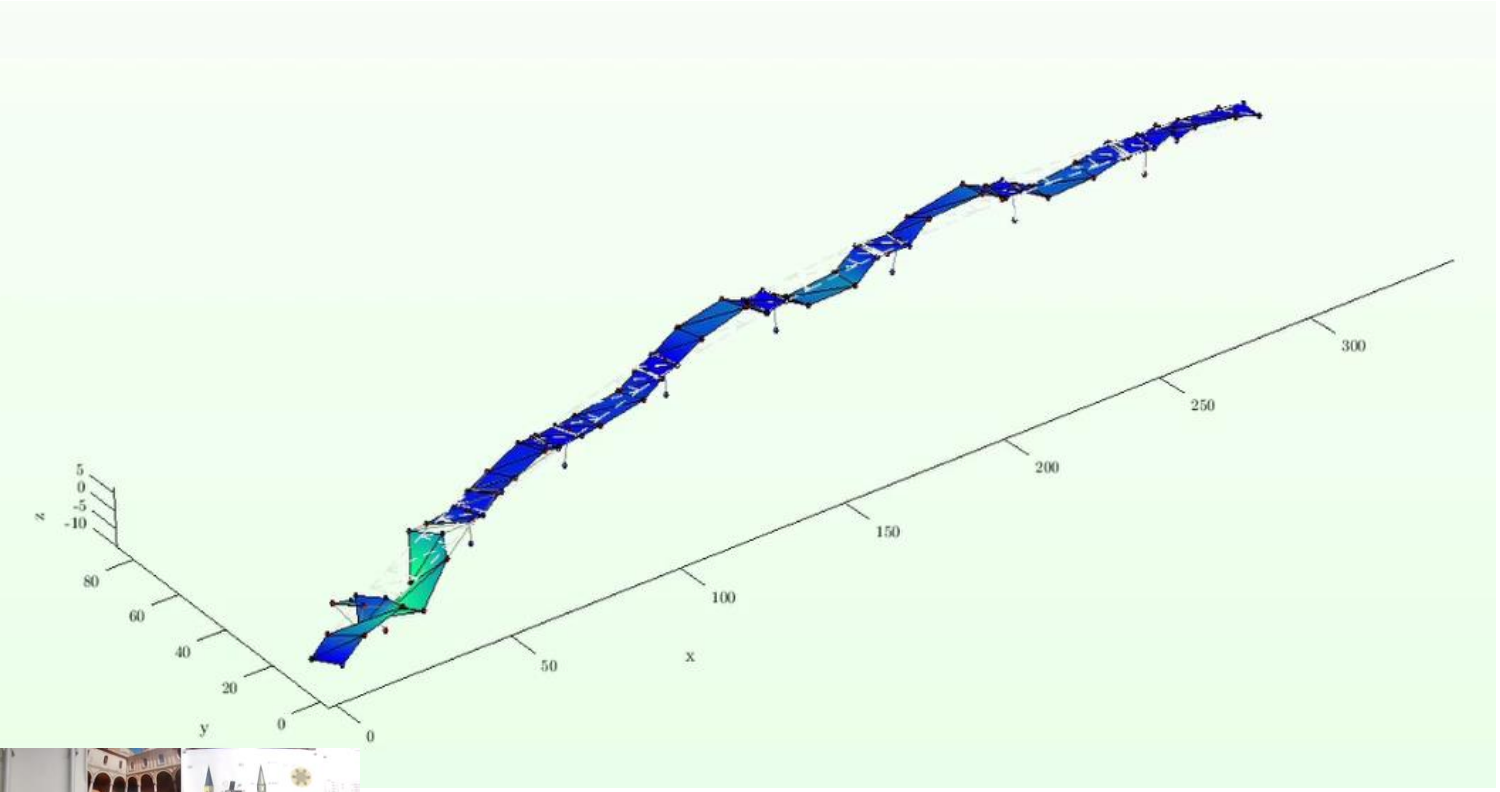


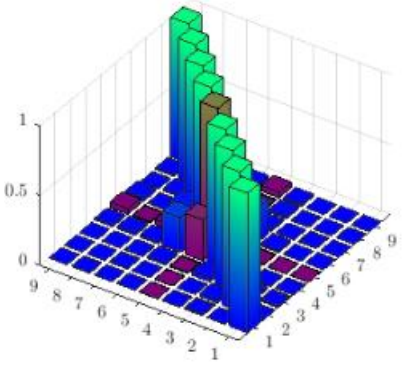
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Mode 5

Example application to San Faustino Bridge



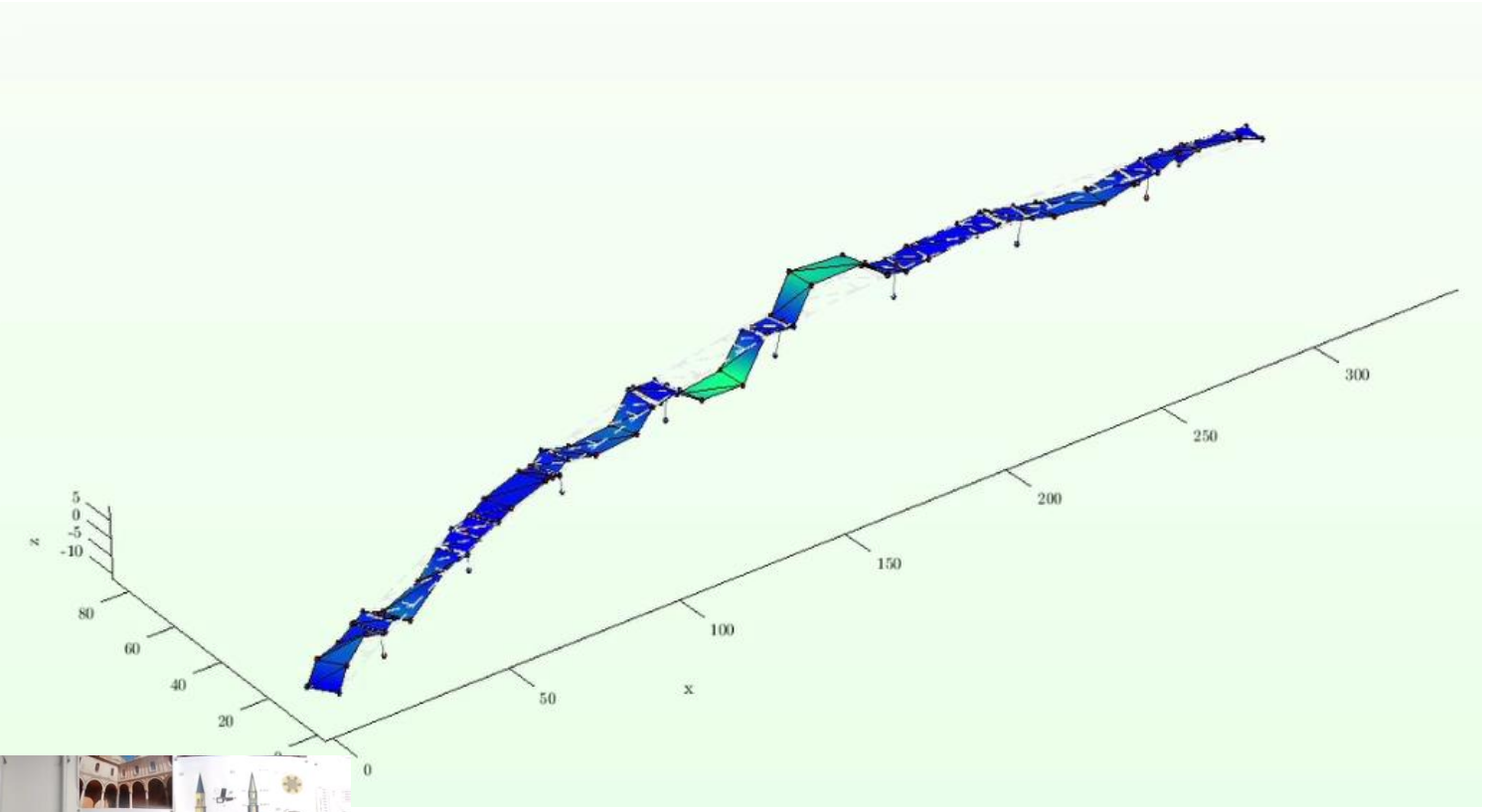


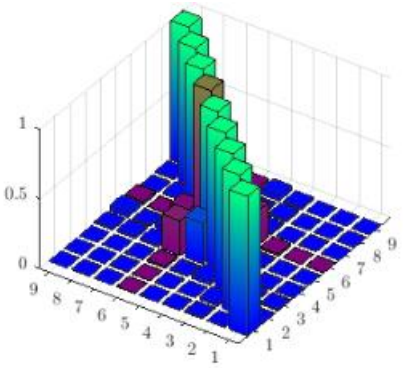
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Mode 6

Example application to San Faustino Bridge



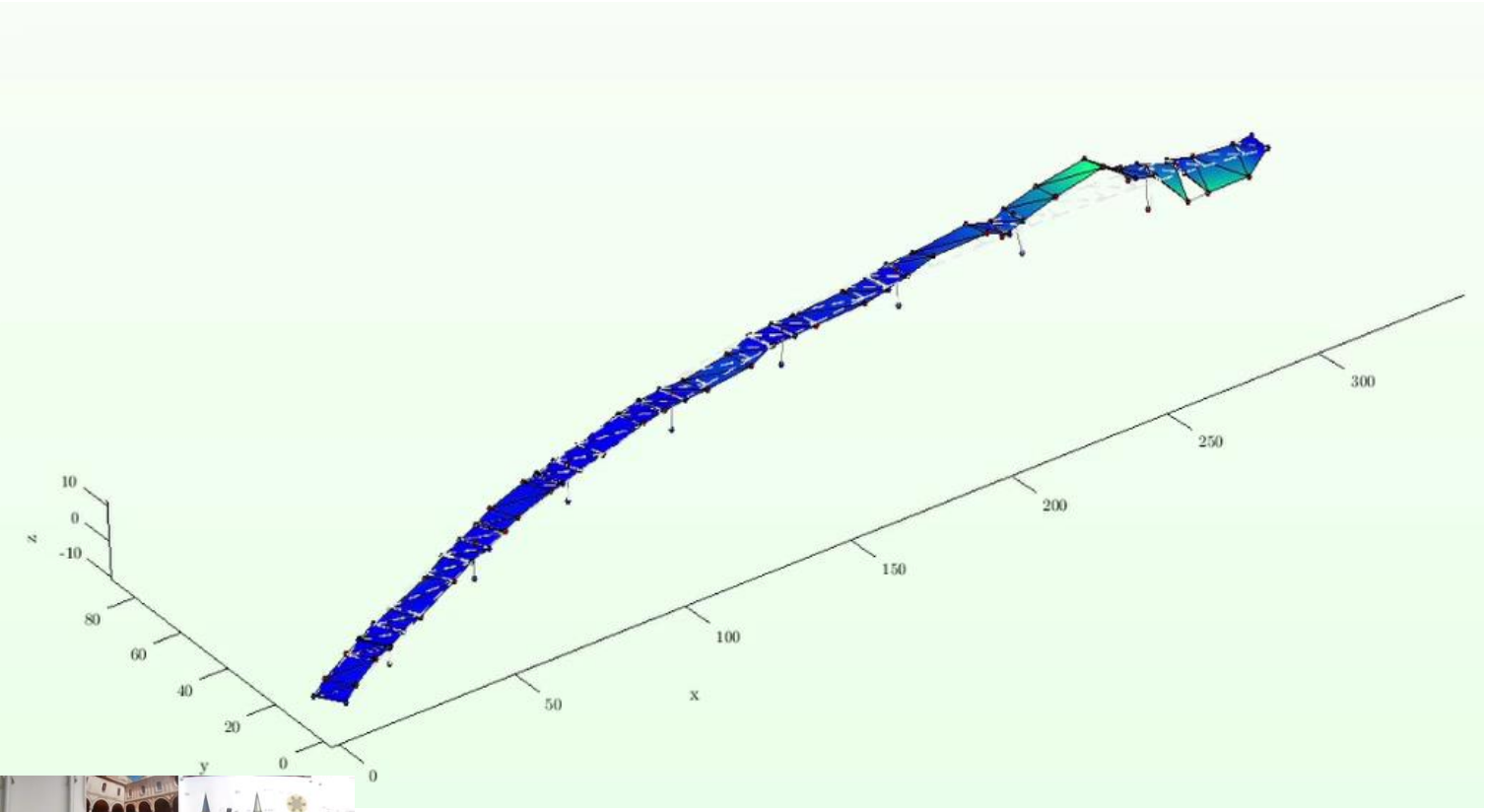


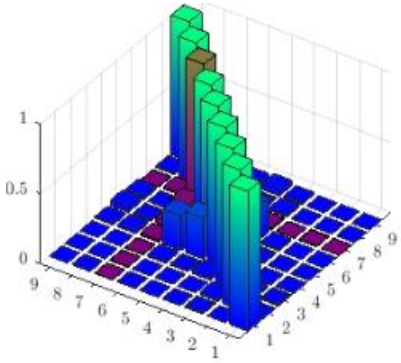
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

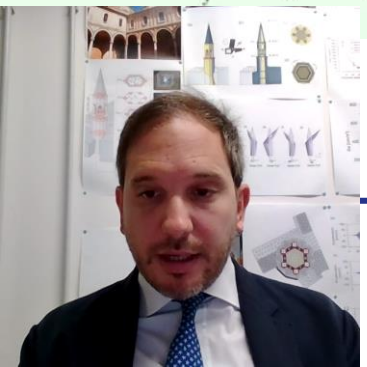
Mode 7

Example application to San Faustino Bridge





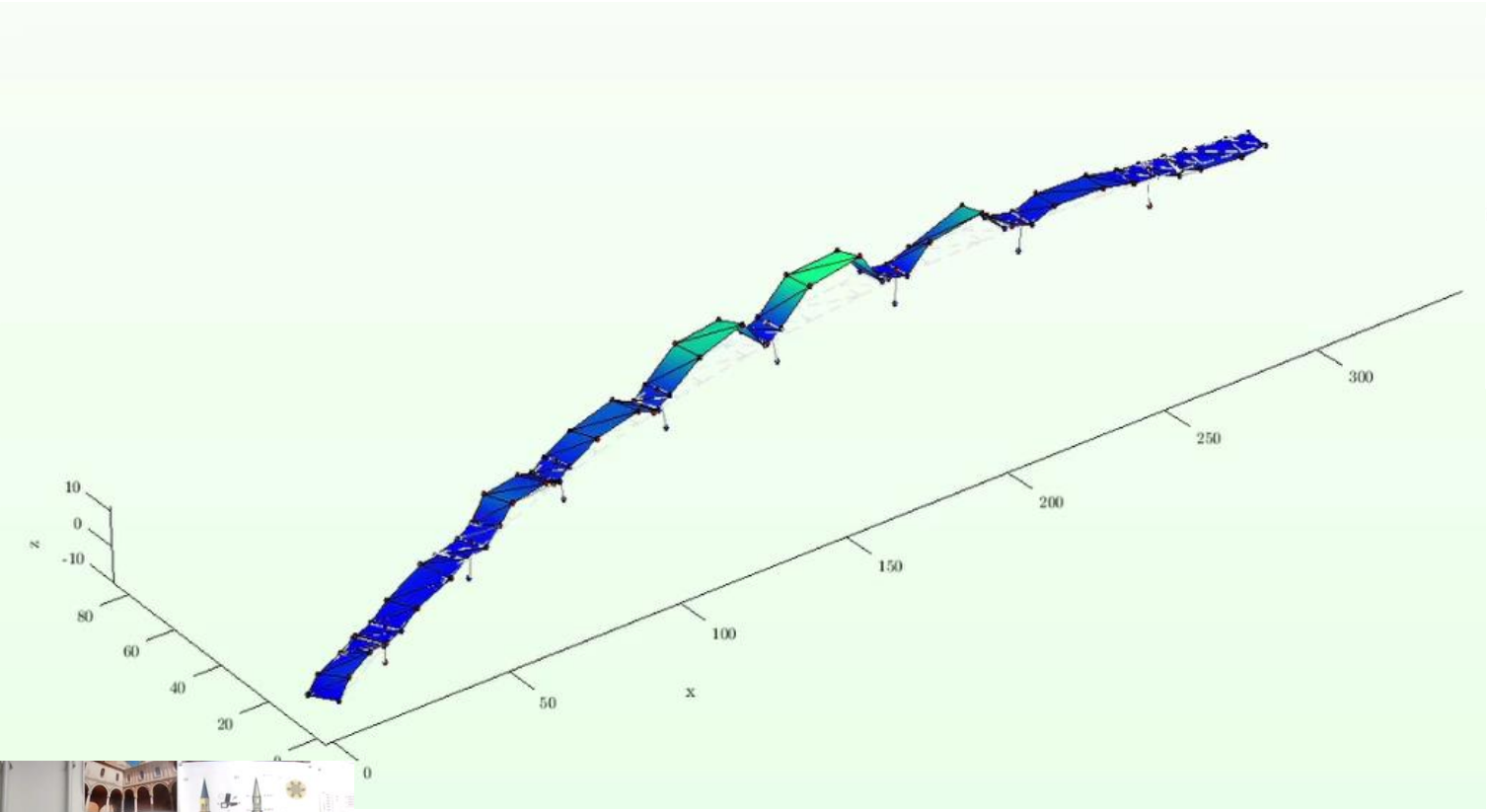
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

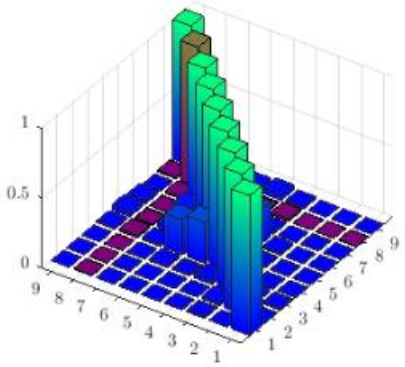


SOFTWARE IMPLEMENTATION: P3P

Mode 8

Example application to San Faustino Bridge



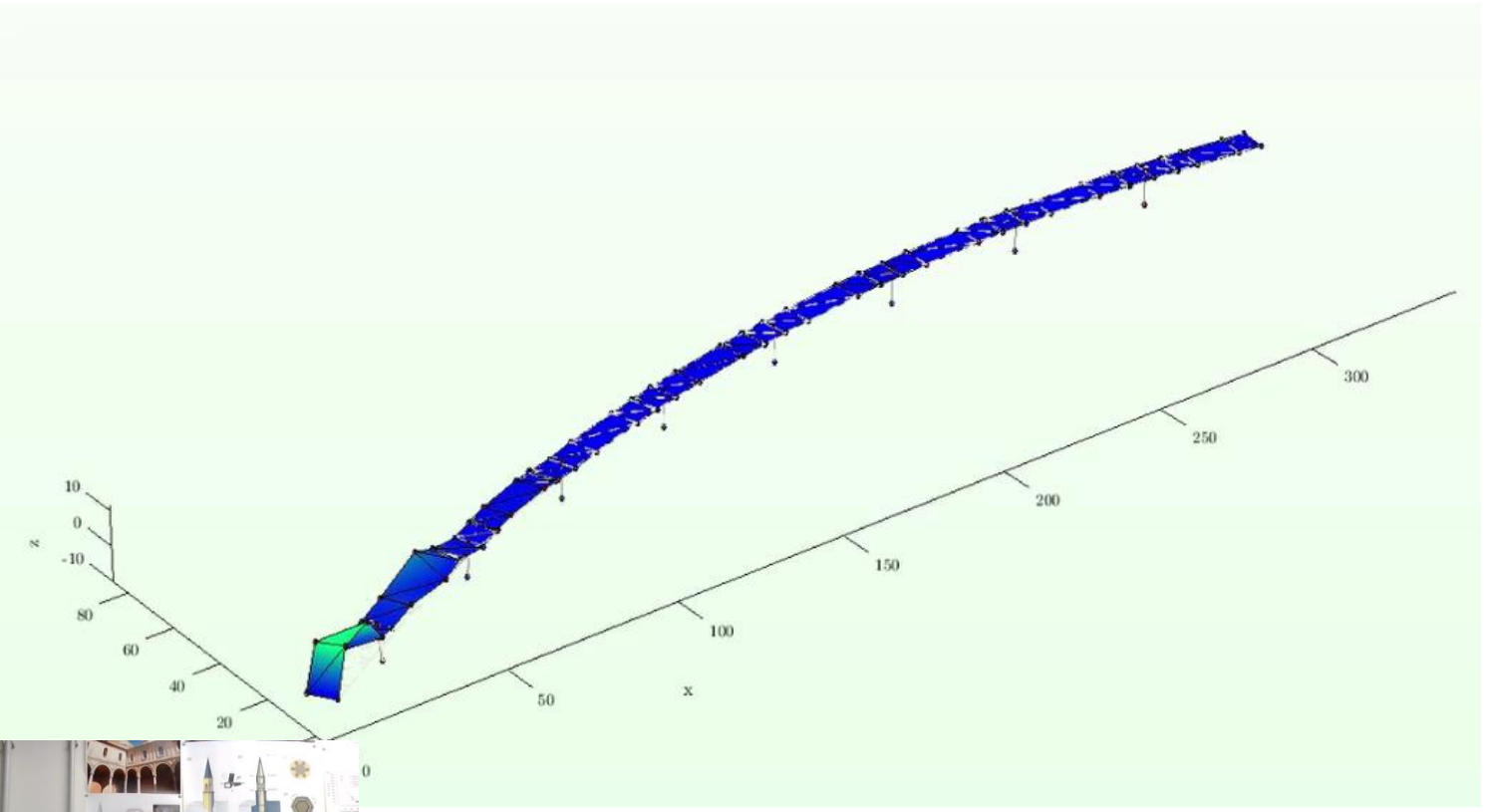


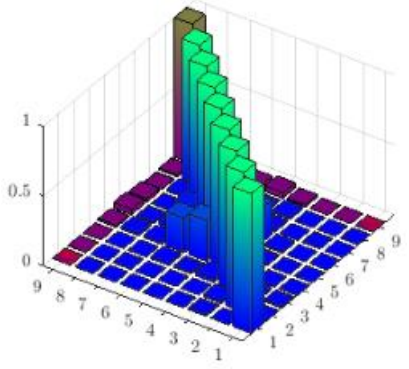
Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Mode 9

Example application to San Faustino Bridge

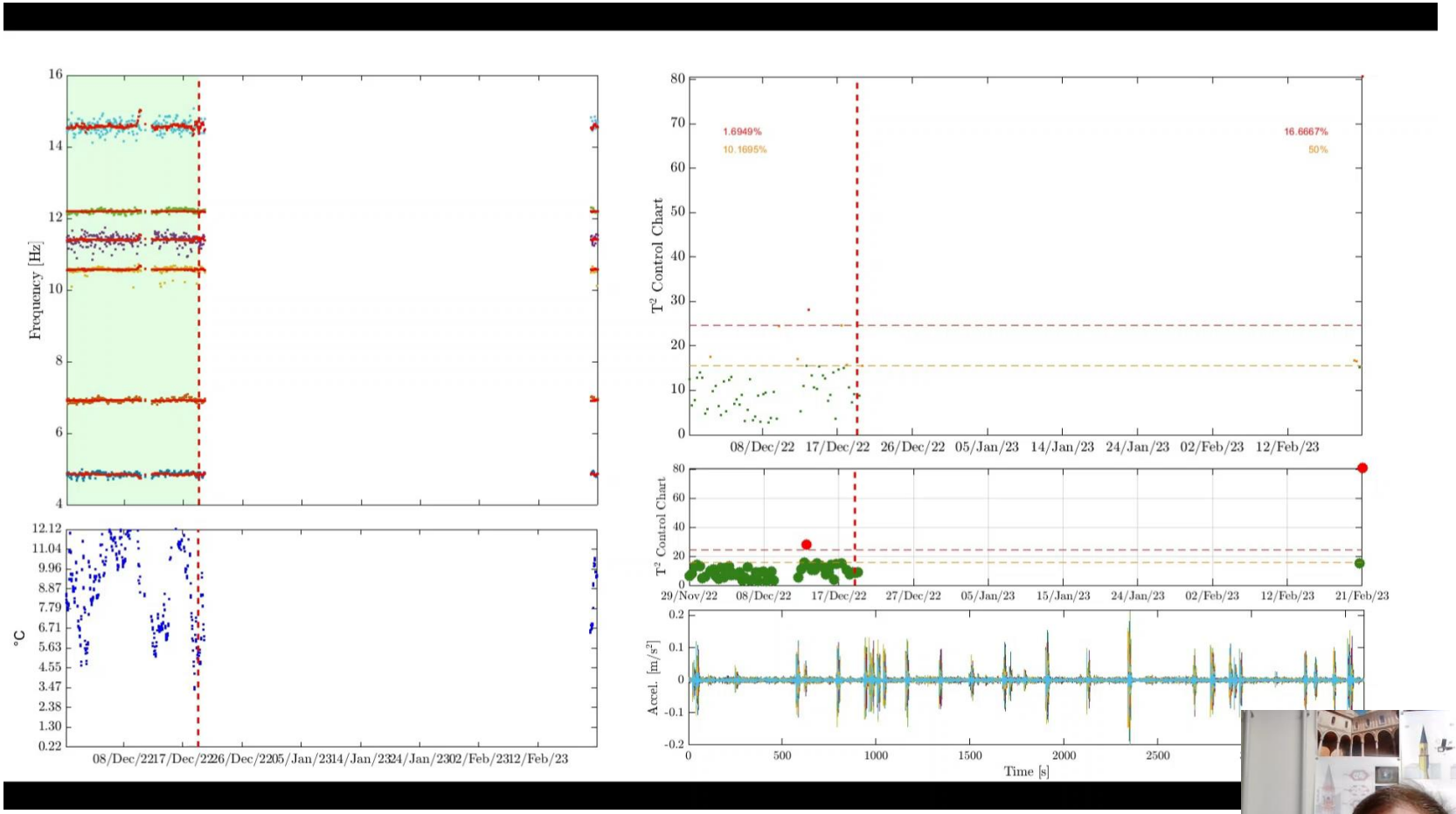




Mode No.	Frequency [Hz]
1	2.6563
2	2.9297
3	3.3008
4	4.1797
5	4.4336
6	4.6680
7	5.1172
8	5.9375
9	6.5234

SOFTWARE IMPLEMENTATION: P3P

Example application to San Faustino Bridge



CONCLUSIONS

- Data science and AI are continuosuly changing the paradigm of data-driven SHM
- Data need to be complemented with engineering knowledge to achieve a direct link from data to decision (model-based SHM)
- Data and case studies are extremely needed for bringing SHM to the next level
- Software implementations have been presented and related challenges have been discussed
- Enormous development in bridge SHM has to be expected in the next years

ACKNOWLEDGEMENTS

Thank you! filippo.ubertini@unipg.it
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