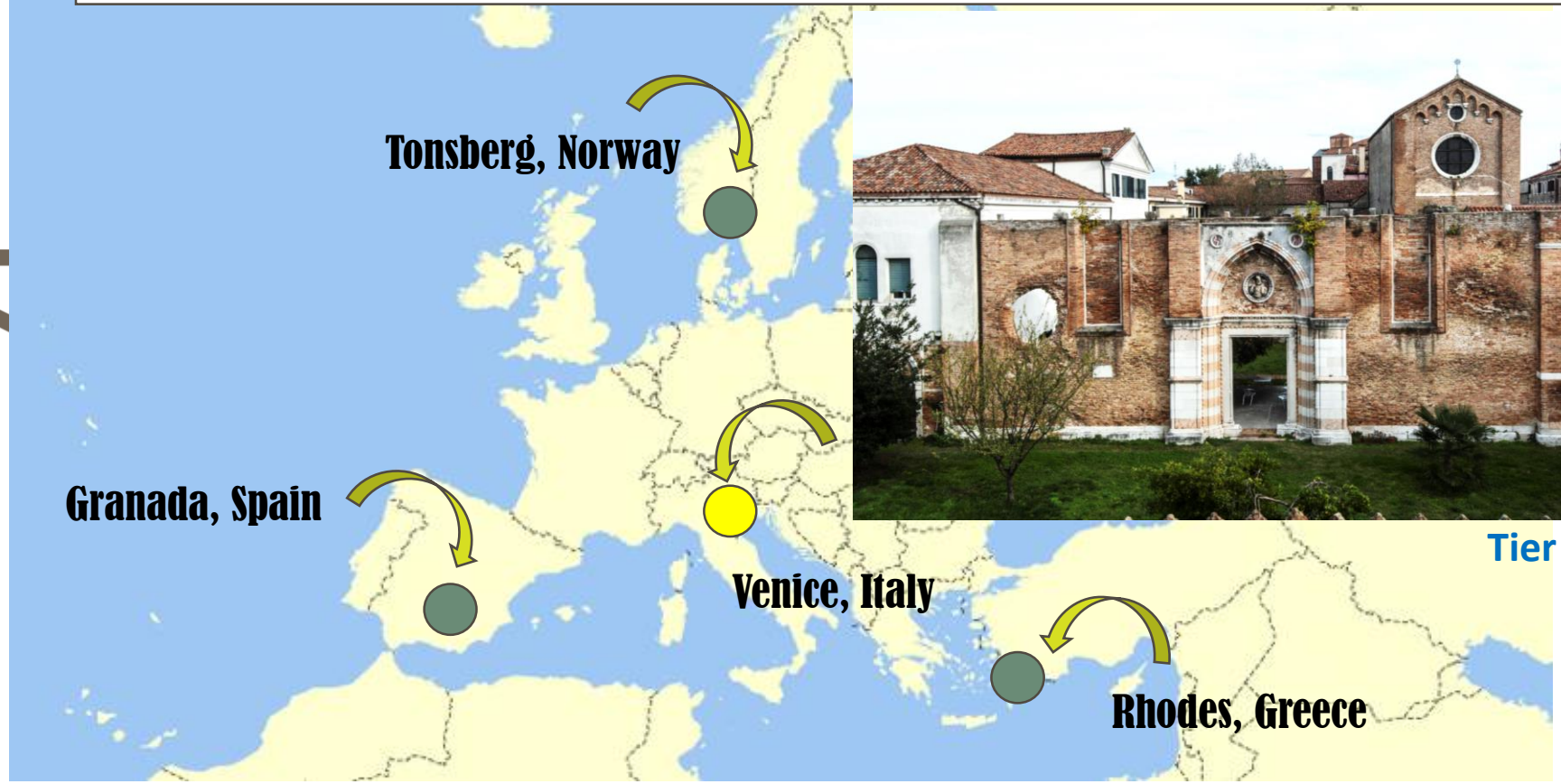
Decay assessment and 3D surface modelling of historical brick masonries in Venice

Chiara Coletti * ([a]), Luigi Germinario ([a]), Enrique Hernández Montes ([b]), Luisa María Gil-Martín ([b]), Lara Maritan ([a]), Jacopo Nava ([a]), Matteo Massironi ([a]), Simone Dilaria ([c]), Gianmario Guidarelli ([d]), Stefano Castelli ([a]) & Claudio Mazzoli ([a])

([a]) Department of Geosciences, University of Padova, Italy
([b]) Department of Dept. Structural Mechanics E.T.S.I. de Caminos, C. and P. University of Granada, Spain
([c]) Department of Cultural Heritage: archeology, history of art, cinema and music (DBC), University of Padova, Italy
([d]) Department of Civil, Construction and Environmental Engineering – ICEA, University of Padova, Italy

HYPERION: Development of a Decision Support System for Improved Resilience & Sustainable Reconstruction of historic areas to cope with the Climate Changes & Extreme Events based on Novel Sensors and Modelling Tools. HORIZON 2020-LC-CLA-2018-2

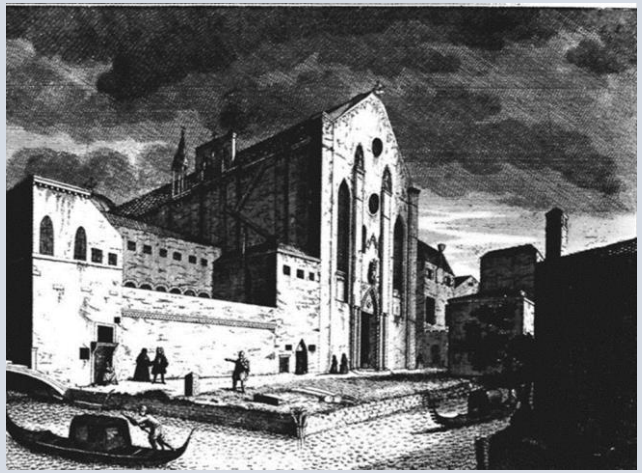


Tier 2-building

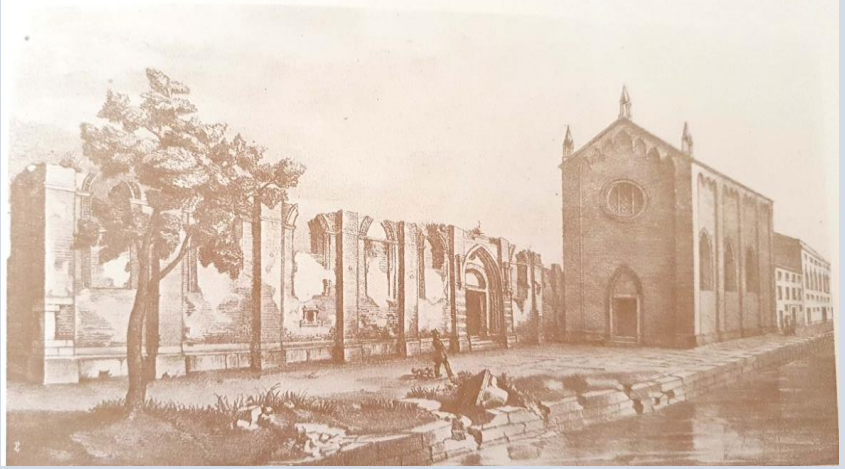
Tier 1-building

24th March 1318 Laying of the first stone - 1330 Construction of the foundations - 7th November 1491 Consecration

J. de'Barbari (1500)



L. Carlevarijs (1703)

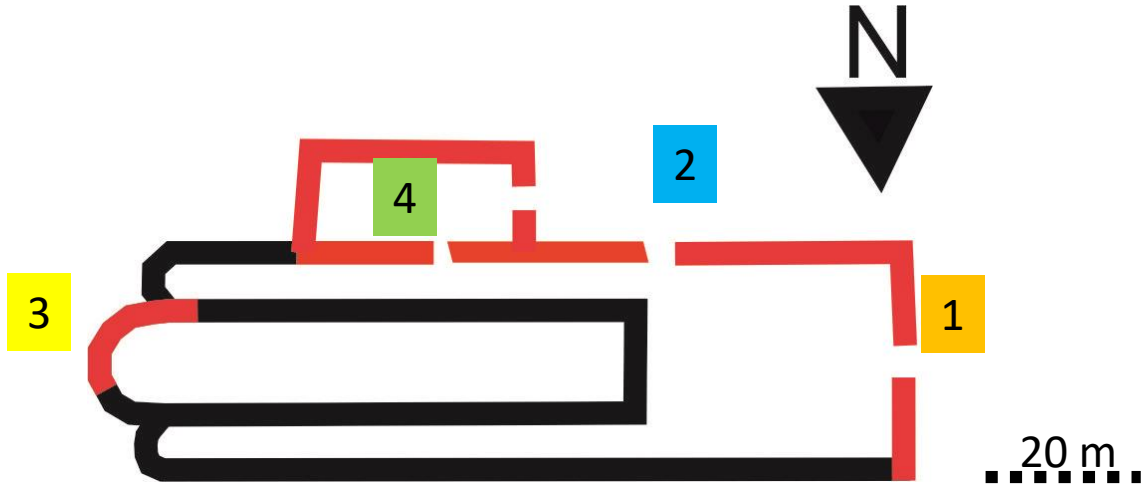


Antonelli-Ribellato (1821)

Santa Maria dei Servi Church

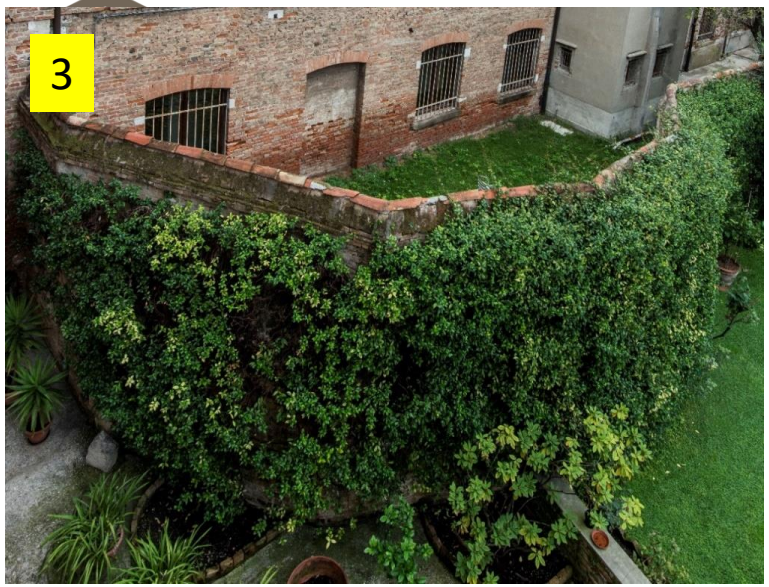
Santa Maria Gloriosa dei Frari (1492)

Basilica dei Santi Giovanni e Paolo (1430)



Plant of the building: in red current ruins, in black lost walls

The westhern (main) façade



The apse

The southern façade

The Volto Santo chapel

Deterioration of the main façade: damage brick mansory; black crust on stones; stone esfoliation; secondary plants

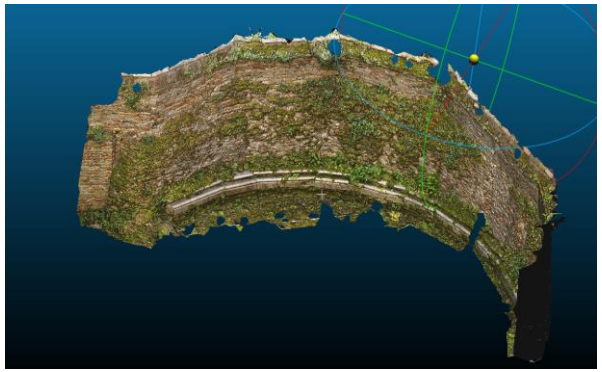





Why Santa Maria as TIER 2 building?

BRICK MADE

COLLECTION OF SAMPLES



3D PHOTOGRAMMETRY

HYPERSPECTRAL ANALYSIS

DETERIORATION PATTERNS

Which are the expected outcomes?

Traditional methods

HISTORICAL AND TECNOLOGICAL INFORMATION

DECAY EVOLUTION

PAST

3D models

SIMULATION OF FUTURE SCENARIOS

FUTURE

On the top: Chapel in Santa Maria dei Servi (Cannaregio), Abazia della Misericordia, campo dell'Abazia, San Sebastiano.
On the bottom: Sant'Apollinare (San Polo). On the bottom, Chapel in Santa Maria dei Servi wall near the canal.

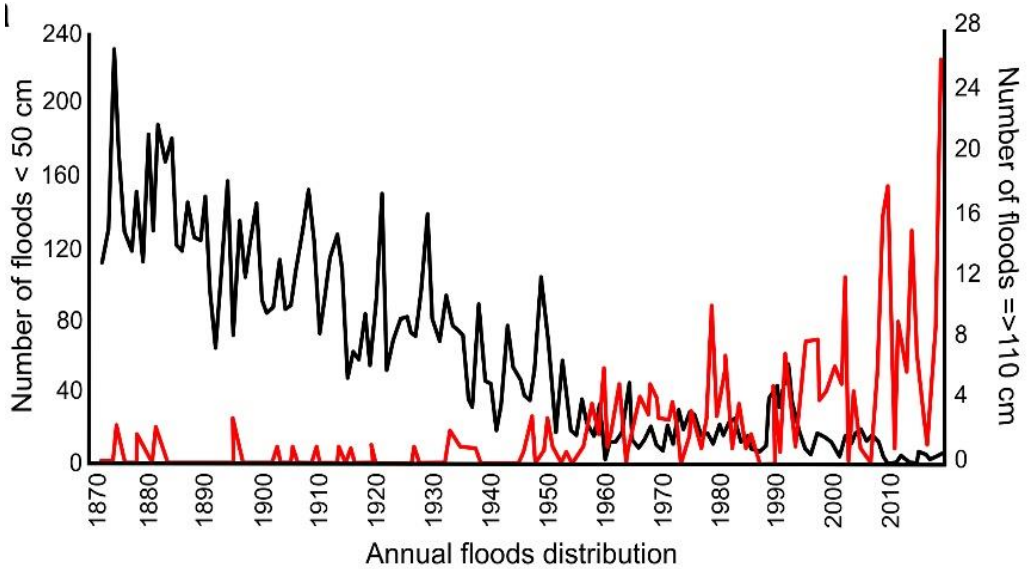
San Giacomo dall'Orio

Basilica dei Frari

Campo dei Frari

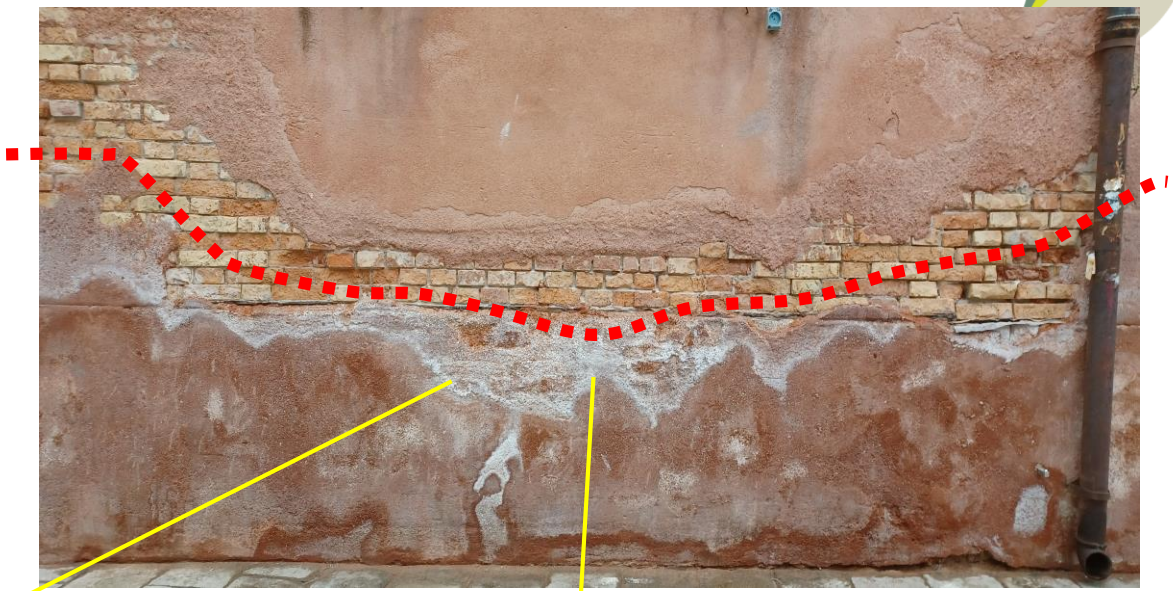
Basilica dei Frari

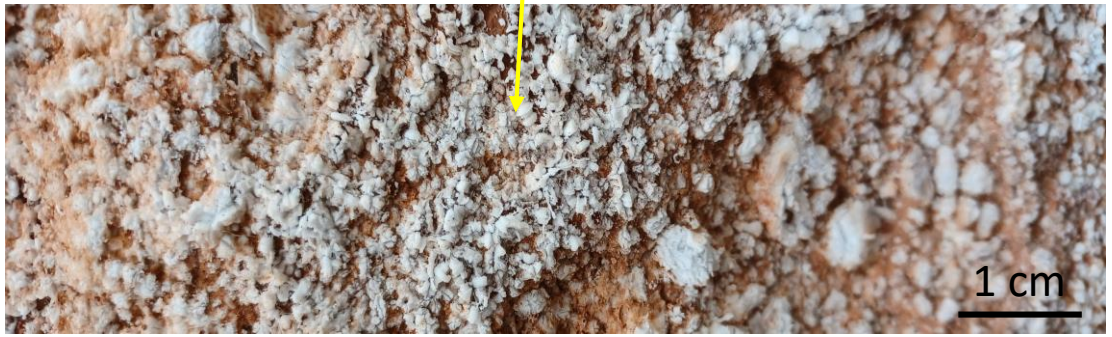
FLOODS, CAPILLARY RISE & SALTS



Yearly distribution of tides < 50 cm recorded in Venice from 1860 to 2020

Santa Fosca Church, Cannaregio



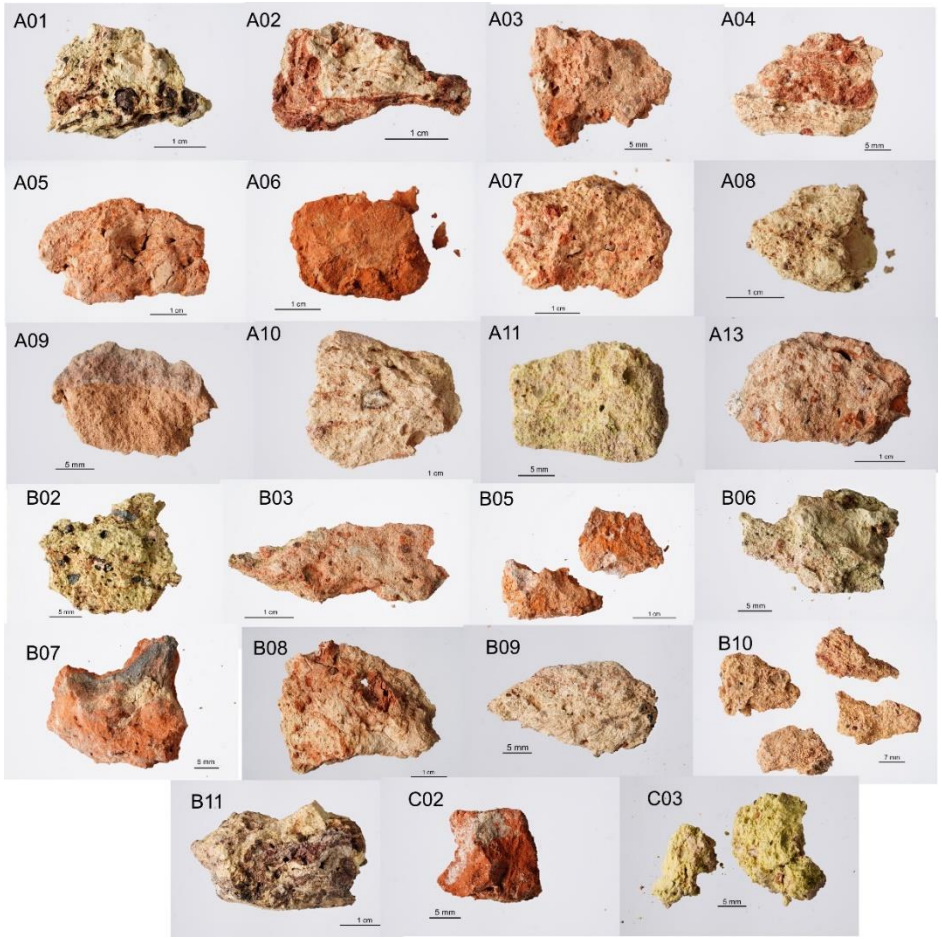


Salt efflorescence, details

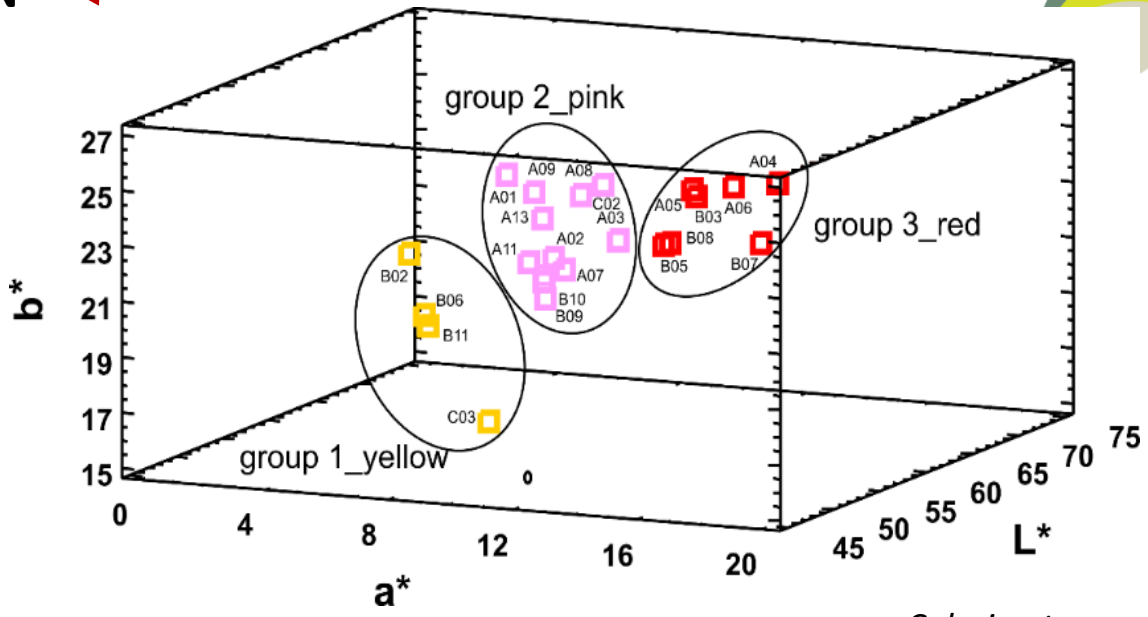
HISTORICAL AND TECNOLOGICAL INFORMATION

PAST

DECAY EVOLUTION



Macroscopic observations



Colorimetry

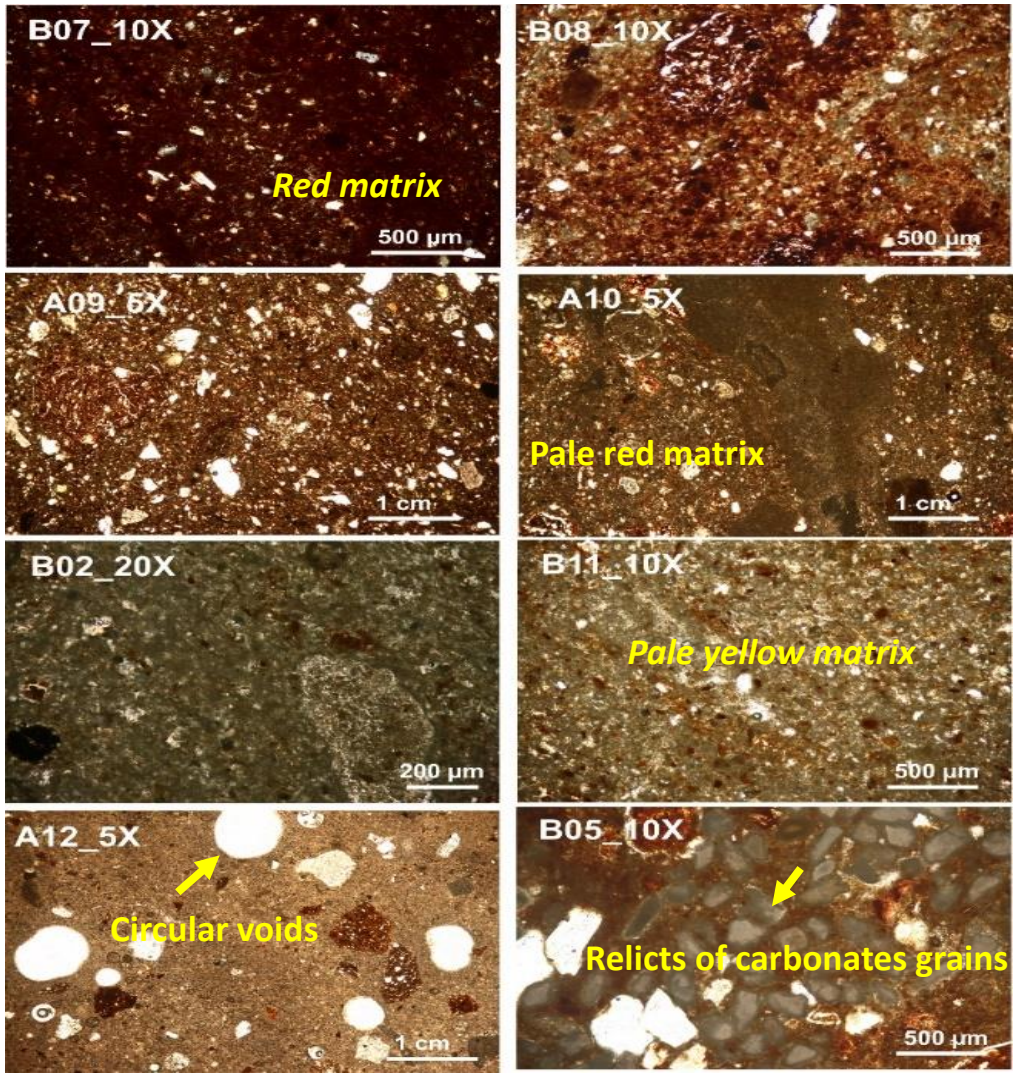
Color:

The colorimetric results in the Lab space bricks (in dry condition) can be defined into three main chromatic groups: yellow-colored bricks (grou1_yellow); pink-colored bricks (group2_pink), and red-colored-bricks (group3_red).

The most abundant category of bricks is the pink-colored (with 12 samples), followed by the red- (7 samples) and the yellow-colored (4 samples).

HISTORICAL AND TECNOLOGICAL INFORMATION

PAST DECAY EVOLUTION



Optical Microscopy

Texture:

- Texturally bricks display similar petrological features
- Very low active groundmass with color ranged between in red or red-brown and in yellow-light brown
- Scarce sub-rounded porous are observed and shrinkage rims were likewise formed, almost filled by secondary calcite.

Mineralogy:

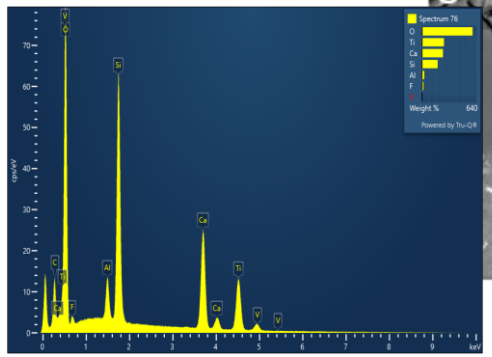
- Most of the crystals detected are minerals of quartz, followed by feldspar grains.
- The presence of residual carbonates (calcite and/or dolomite) suggested that firing process does not reach temperature above 800-850°C, at which they decomposed.

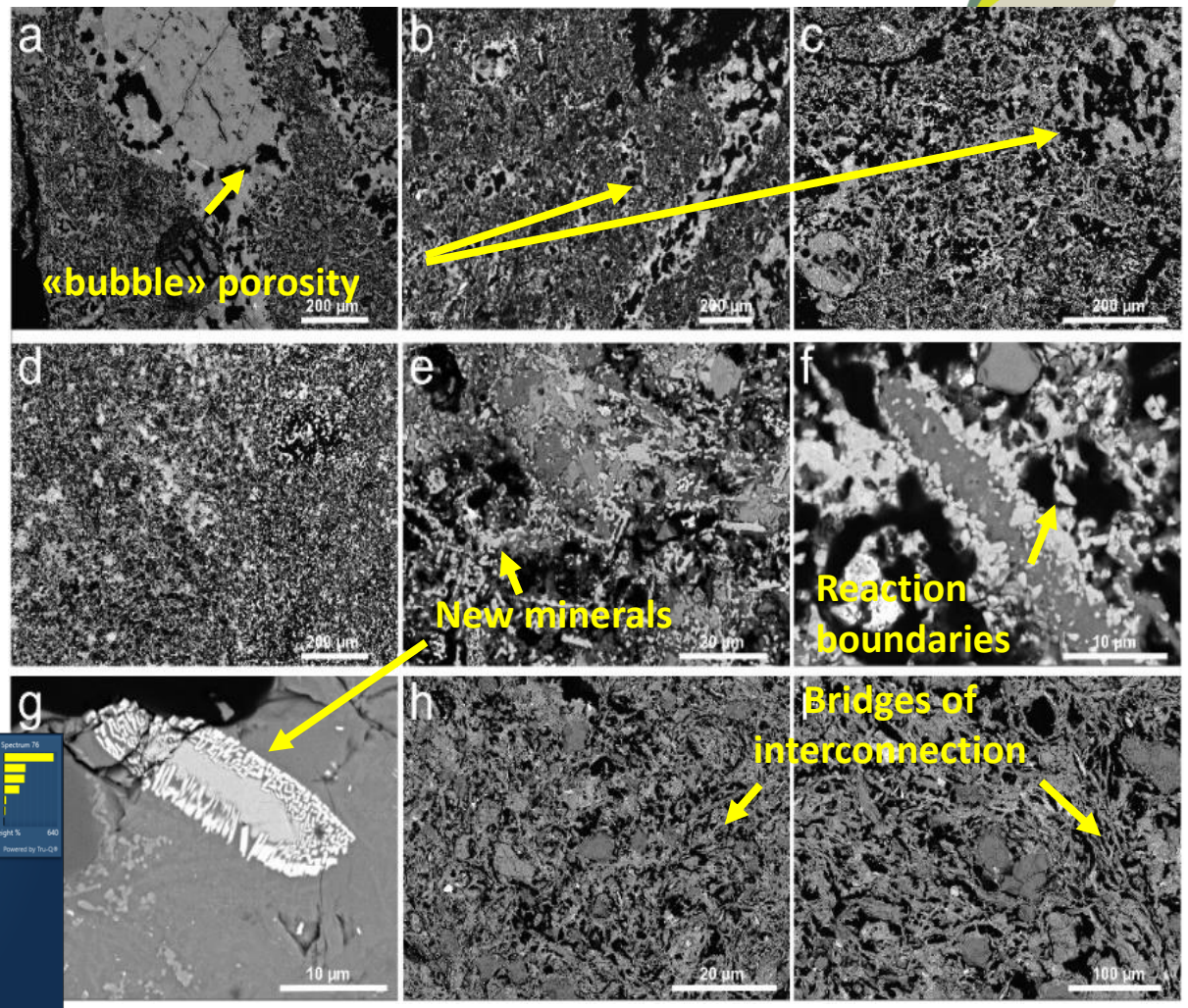
Texture:

- The textural observation carried out with FESEM in a set of five selected samples (A4, A8, B2, B6 and B10) validated the considerations drawn from the MOP analysis. Samples are overall characterized by a high porosity, with a prevalence of micro and meso pores, and an inhomogeneous texture.

Mineralogy:

- New silicate phases with heavy elements (in particular Ti): titanite grains and fassaite.
- Mineralogy is coherent to the Venice lagoon sediments, where is also present Ti (Busà, 2010).



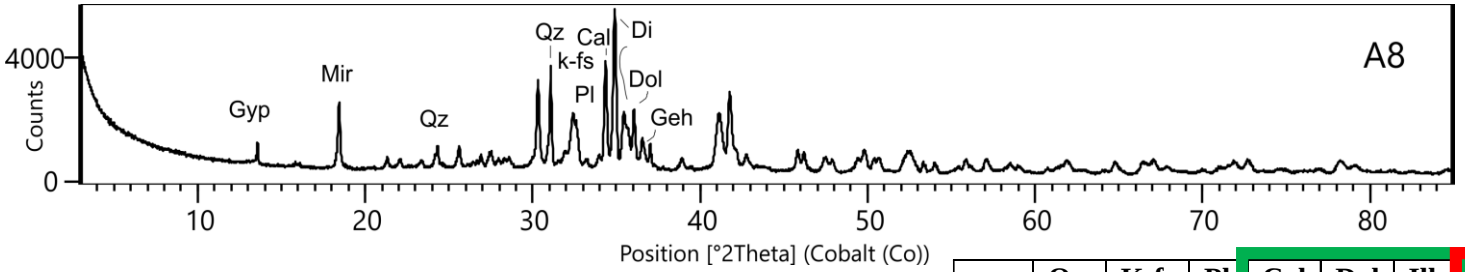


Scanning Electron Microscopy

HISTORICAL AND TECNOLOGICAL INFORMATION

PAST

DECAY EVOLUTION



X-ray Powder Diffraction

Mineralogy and brick technology:

- Relative abundance of primary minerals (i.e. calcite and dolomite) and secondary firing minerals (i.e. diopside, gehlenite and fassaite) suggesting a certain temperature higher than 800-850°C and homogeneity in raw materials used.

- Most of samples have also peaks of calcite, some of them display dolomite and illite. The presence of these phases indicate that temperature does not exceed the 850°C.

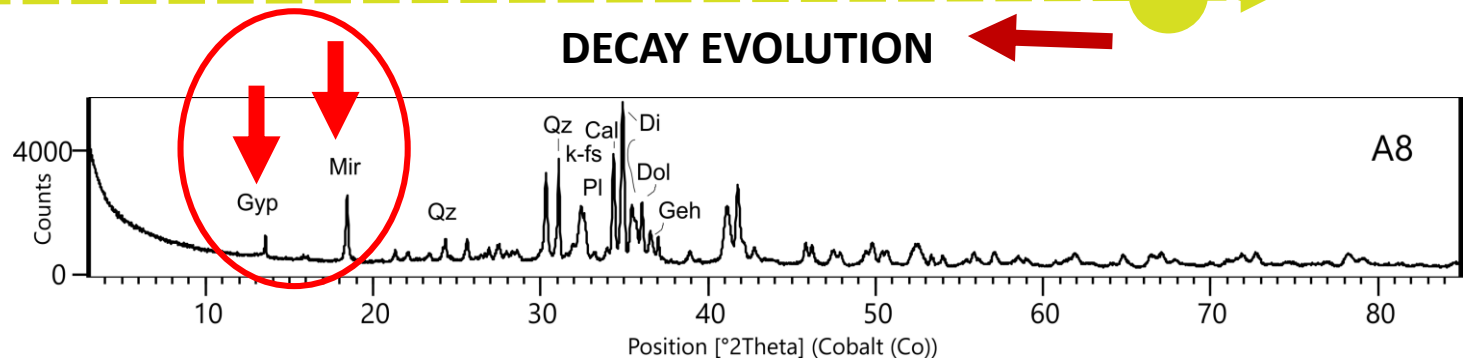
	Qz	K-fs	Pl	Cal	Dol	Ill	Di	Geh	Fas	Gyp	Mir	Hem	Group
A1	xxx	x	x		x		xx			*		*	group2_pink
A2	xxx		xx				xxx	*				*	group2_pink
A3	xxx	x	x	x	**	**	**			*		*	group2_pink
A4	xx		xx	xx			xxx		**	*	x	*	group3_red
A5	xxx	x	x	**		*				*	x	*	group3_red
A6	xxx	x	x	xx		*	*			*		*	group3_red
A7	xx	x	x	xx			xx		**	**	*	*	group2_pink
A8	xx	x	x	xx	**		xxx		**	**	xx	*	group2_pink
A9	xxx	x	xx				xx					*	group2_pink
A10	xx	x	xx	x			xxx			*	x	*	group2_pink
A11	xx	x	xx	x			xxx			**	xx	*	group2_pink
A13	xxx	x	xx	x			xx			xx	*	*	group2_pink
B2	x	*	xx				xxx			xx	xx	*	group1_yellow
B3	xxx	x	x		x		x					*	group3_red
B5	xxx	*		xx	x	*				**		*	group3_red
B6	xx	xx	xx	xx			xxx		**	x	x	*	group1_yellow
B7	xxx		x		*	*				*		*	group3_red
B8	xxx		xx		x		xx			*	*	*	group3_red
B9	xxx	x	xx		x		xx			x	*	*	group2_pink
B10	xxx		xx	*	**		xx		xx	xxx		*	group2_pink
B11	xxx	x	xx				xx			xx	*	*	group1_yellow
C2	x		xx				xxx	*		xxx	xx		group2_pink
C3	xxx	x	x	xx						x	*		group1_yellow

Mineralogical assemblages in historical bricks from XRPD analysis. Mineral abbreviations after Whitney and Evans (2010): Qz = quartz; Ill = illite; Kfs = K-felspar; Pl = Plagioclase; Cal = calcite; Dol = dolomite; Hem = Hematite; Di = diopside; Gh = gehlenite; Fas = Fassaite; Gyp = gypsum; Mir = mirabilite. Relative quantity: xxx = very abundant; xx = abundant; x = medium; ** = scarce; * = rare.

HISTORICAL AND TECNOLOGICAL INFORMATION

DECAY EVOLUTION

PAST



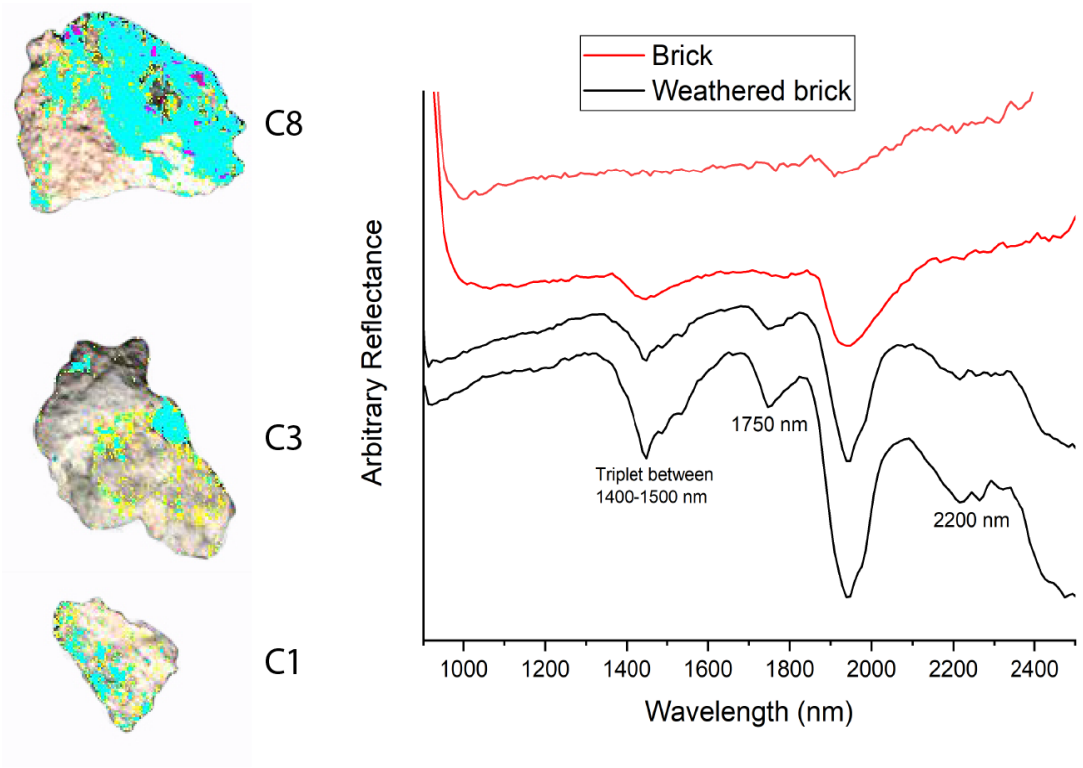
X-ray Powder Diffraction

- Gypsum or mirabilite are often found by diffraction patterns. These results are consistent with previous literature which indicate gypsum, halite and mirabilite as the main weathering products due to the salt decay process that affects Venice and the lagoon environment (Antonelli, et al., 2002; Schiavon, et al., 2008).

	Qz	K-fs	Pl	Cal	Dol	Ill	Di	Geh	Fas	Gyp	Mir	Hem	Group
A1	xxx	x	x		x		xx			*		*	group2_pink
A2	xxx		xx				xxx	*				*	group2_pink
A3	xxx	x	x	x	**	**	**			*		*	group2_pink
A4	xx		xx	xx			xxx		**	*	x	*	group3_red
A5	xxx	x	x	**		*				*	x	*	group3_red
A6	xxx	x	x	xx		*	*			*		*	group3_red
A7	xx	x	x	xx			xx		**	**	*	*	group2_pink
A8	xx	x	x	xx	**		xxx		**	**	xx	*	group2_pink
A9	xxx	x	xx				xx					*	group2_pink
A10	xx	x	xx	x			xxx			*	x	*	group2_pink
A11	xx	x	xx	x			xxx			**	xx	*	group2_pink
A13	xxx	x	xx	x			xx			xx	*	*	group2_pink
B2	x	*	xx				xxx			xx	xx	*	group1_yellow
B3	xxx	x	x		x		x					*	group3_red
B5	xxx	*		xx	x	*				**		*	group3_red
B6	xx	xx	xx	xx			xxx		**	x	x	*	group1_yellow
B7	xxx		x		*	*				*		*	group3_red
B8	xxx		xx		x		xx			*	*	*	group3_red
B9	xxx	x	xx		x		xx			x	*	*	group2_pink
B10	xxx		xx	*	**		xx		xx	xxx		*	group2_pink
B11	xxx	x	xx				xx			xx	*	*	group1_yellow
C2	x		xx				xxx	*		xxx	xx		group2_pink
C3	xxx	x	x	xx						x	*		group1_yellow

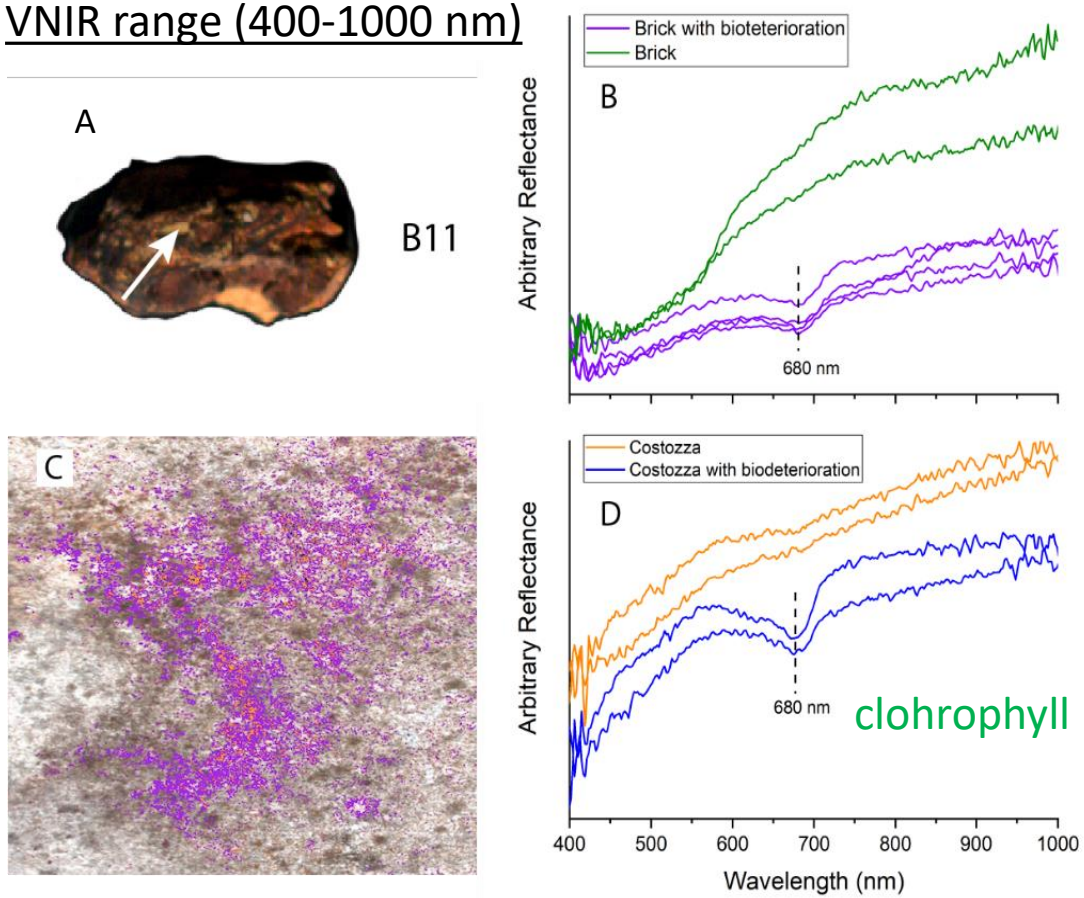
Mineralogical assemblages in historical bricks from XRPD analysis. Mineral abbreviations after Whitney and Evans (2010): Qz = quartz; Ill = illite; Kfs = K-felspar; Pl = Plagioclase; Cal = calcite; Dol = dolomite; Hem = Hematite; Di = diopside; Gh = gehlenite; Fas = Fassaite; Gyp = gypsum; Mir = mirabilite. Relative quantity: xxx = very abundant; xx = abundant; x = medium; ** = scarce; * = rare.

SWIR range (900-2500 nm)



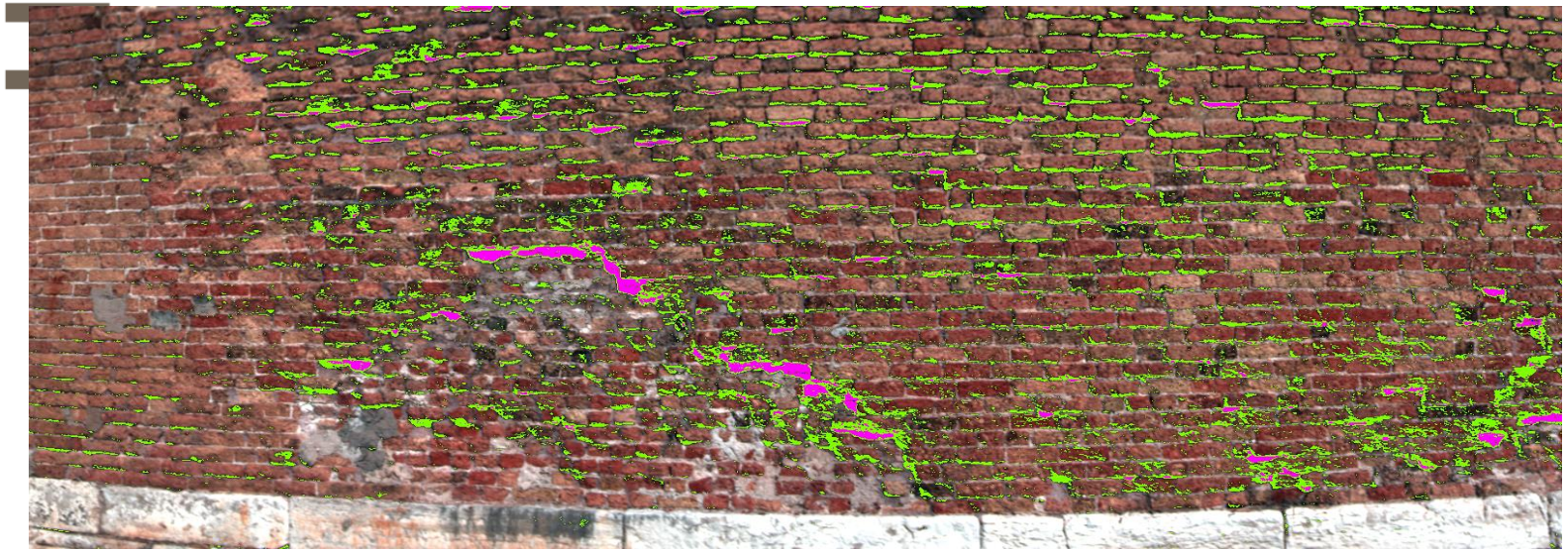
In the spectra of the weathered bricks there are many features of the sulphates spectra, absent in the original spectra. These bands are the triplet between 1400-1500 nm, the 1750 nm and the 2200 nm band.

VNIR range (400-1000 nm)

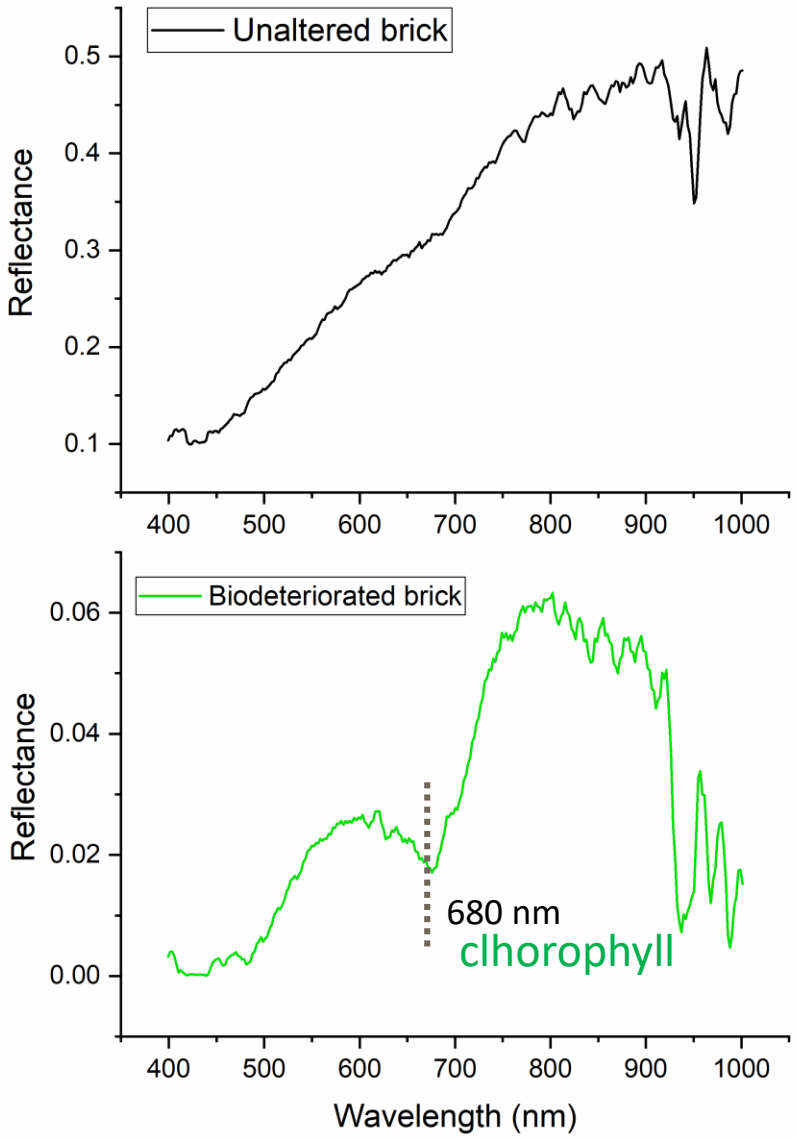


A) brick sample, white arrow indicates a greenish vein where spectra indicates the presence of biodeterioration. B) Spectra of the brick with and without biodeterioration. C-D) Biodeterioration on a Costozza tile indicated by the 680 nm band.

ON SITE ANALYSIS: maps of clhorophyll = biodeterioration



VNIR ranges-hyperspectral analysis




https://sketchfab.com/3d-models/smnds-a0f7a73f712e49e98c9de7707c876710

The empirical methodology

The proposed methodology consists on a system n+1 non-linear of equations which can be solved without considering laboratory data if sufficient information from degraded heritage buildings is available.

Climatic parameters (cp_I)

cp_1=Relative humidity (RH)
cp_2=Salt in soil (ss)
cp_3=Temperature (T)
cp_4=Wind (wd)
cp_5=Freezing days (fd)
cp_6 =annual precipitation (R)
cp_7 =direct irradiance (I)
....
cp_n = climatic parameter n

- Time (t)

Unified Climatic Parameter

$$UCP= \sum_{i=1}^{n} a_i cp_i$$

Observed Engineering Degraded Parameter

=

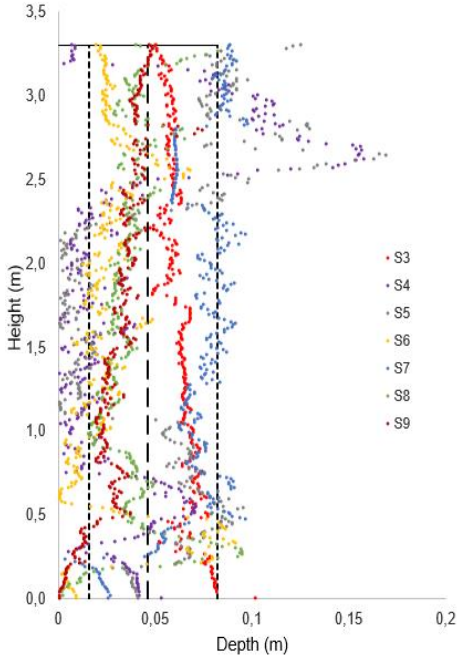
$$t\ EDP(a_1cp_1, \dots , a_ncp_n)= t\cdot\xi\cdot Tan[UCP]$$

a_i = the weighting coefficients for a particular building material

Cp_i = climatic parameter

Flow chart corresponding to the empirical method

Deterioration is formulated from Eq. (3) considering as climatic parameters: salt-crystallization effect in terms of the peak **sun hours per day (n_{psh})**, **annual precipitation in terms of relative humidity (RH)**, and the number of freeze-thaw cycles per year, which in this case is considered to be the number of **frosty days per year (n_{fdy})**:



$$OEDP = t \cdot \xi \, Tan[a_1 n_{fdy} + a_2 RH + a_3 \, n_{psh}]$$

W Average recession of 0.046 m

$$46 = 692 \cdot \xi \, Tan[0.000734 \, n_{fdy} + 0.0497 \, RH + a_3 \, 1.49]$$

Note that Eq. (8) has two unknowns: the salt-crystallization weighting coefficient (a_3) and ξ.

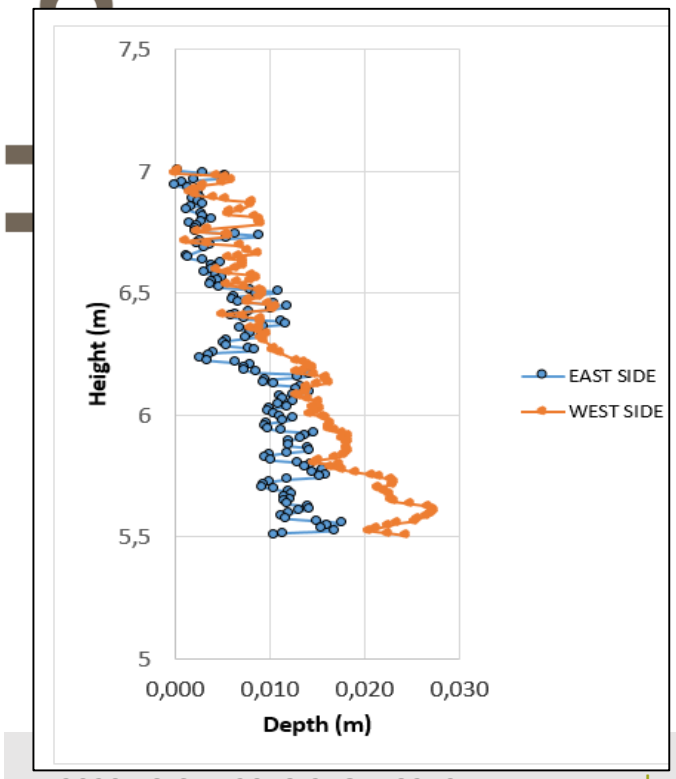
The east façade has been highly altered along history, being difficult to obtain a recession rate associated exclusively to climatic actions. Due to the above, the study is focused on the upper part of Section 3 (S3), at both sides of the wall, which seems not to be intentionally modified, see Figures 10 and 12.

SIMULATION OF FUTURE SCENARIOS

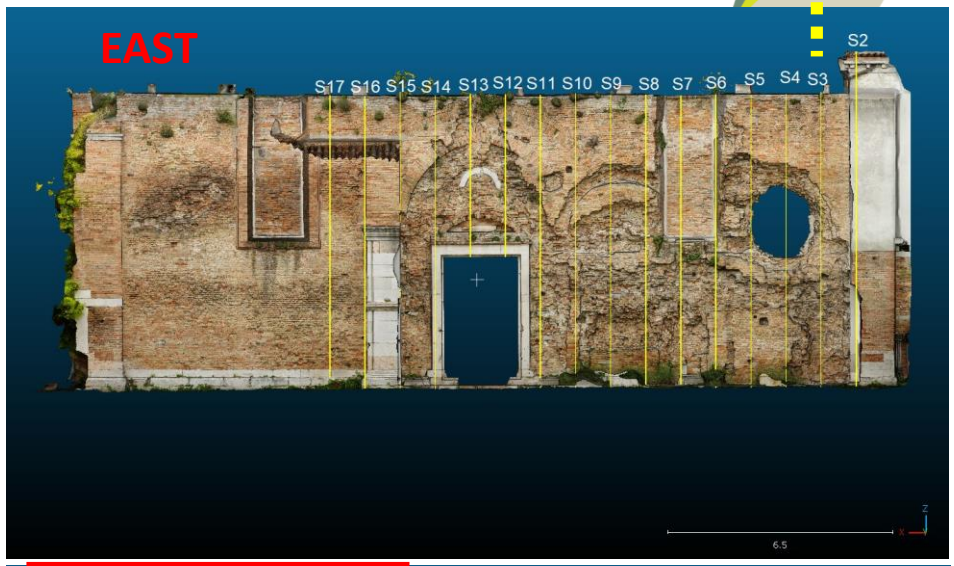
FUTURE

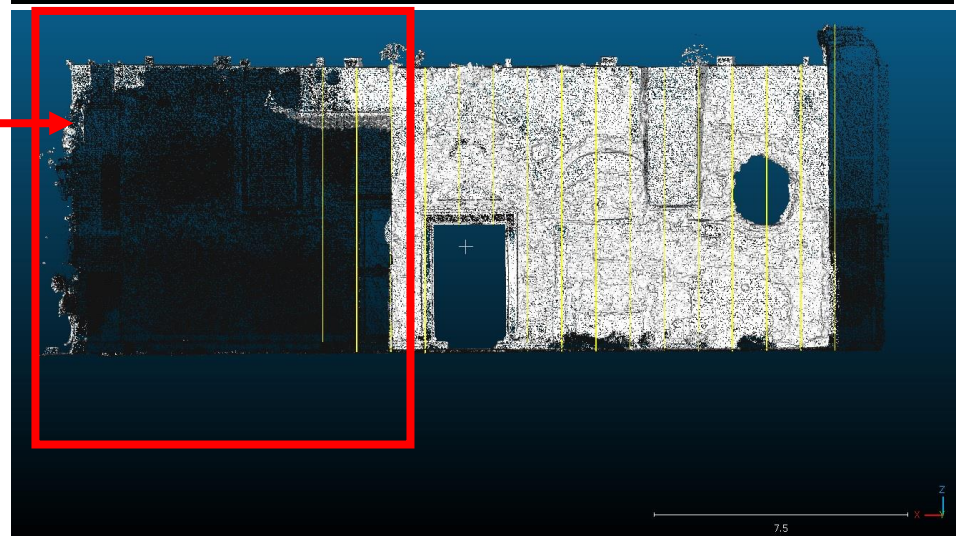
The east façade has been highly altered along history, being difficult to obtain a recession rate associated exclusively to climatic actions. Due to the above, the study is focused on the upper part of Section 3 (S3)

The difference between both sides along the selected part on the top of section S3 is 4.375 mm

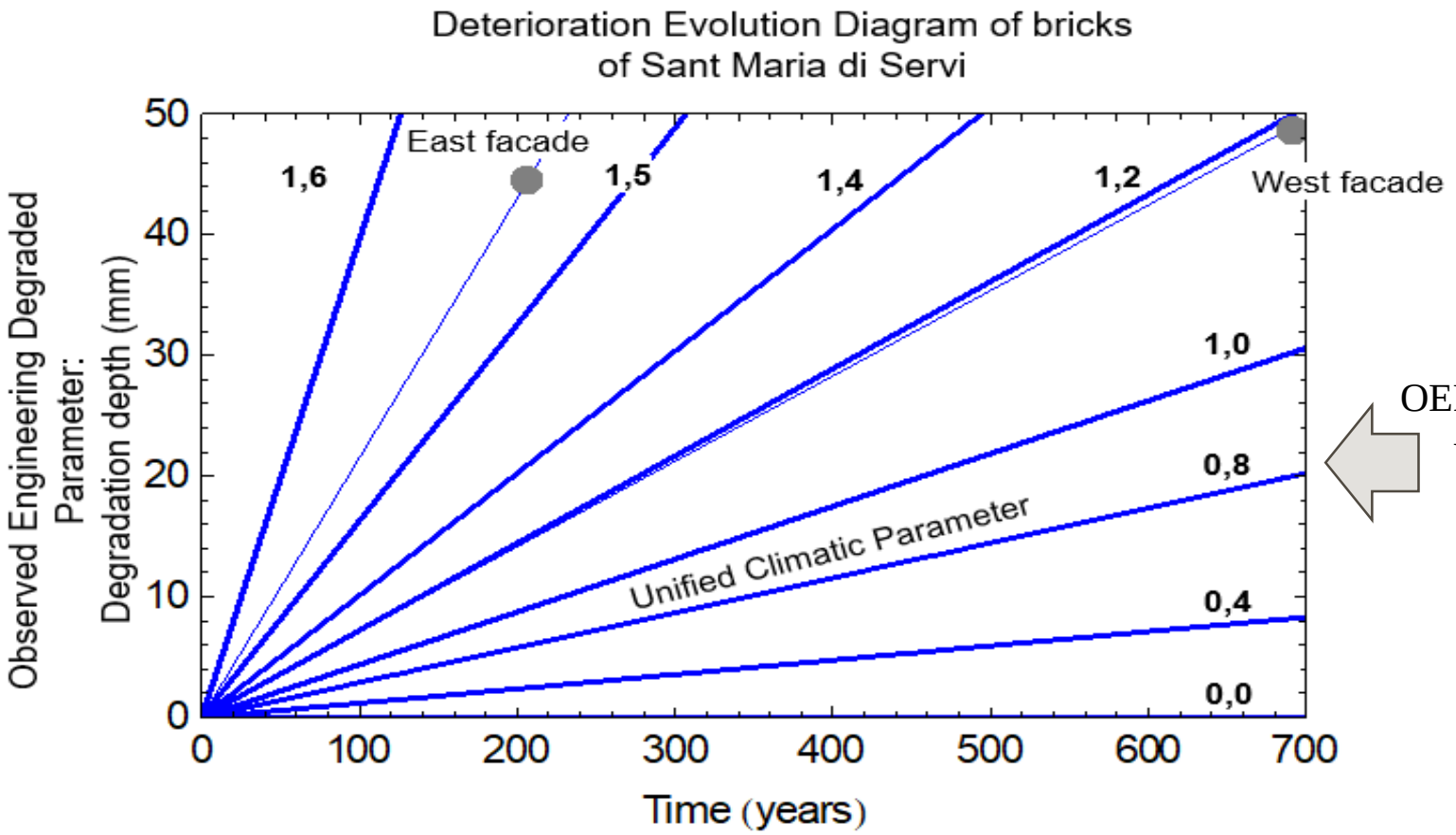


since 1815





THE HYBRID DETERIORATION EVOLUTION DIAGRAM



$$OEPD = 0.0265 \cdot t \cdot Tan[UPC]$$

$$UPC = 0.000734 n_{fdy} + 0.0494 RH + 0.7750 n_{psh}$$

The graphical representation of the OEDP as a function of time and of the UPC.

CONCLUSIONS

HISTORICAL AND TECNOLOGICAL INFORMATION

PAST

DECAY EVOLUTION

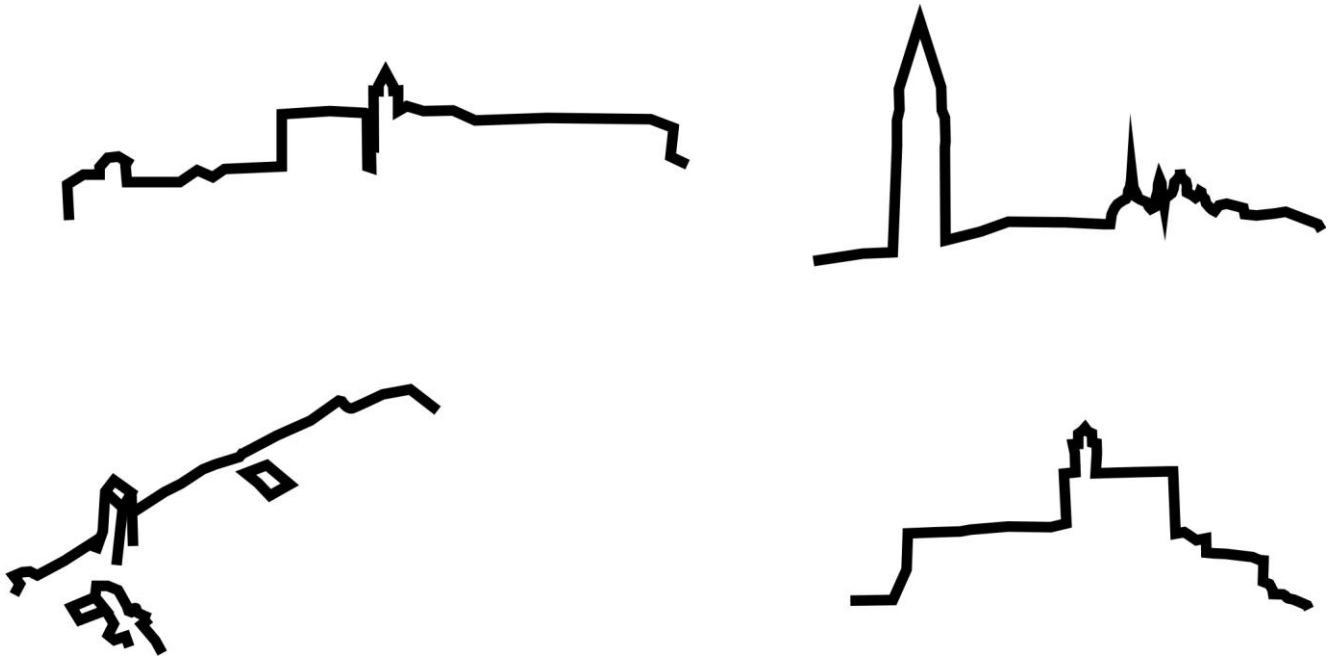
- The consistence of carbonates and new silicate phases suggested the absence of a good standardization in the firing process.
- Ti phases suggest the use of local lagoon sediments for the brick production, confirmed also by the presence of fassaite as new silicate mineral formed during the firing process. This support the theory that in the 14th century there was a first phase of local production of bricks using local clay of the lagoon.
- Gypsum and mirabilite are largely found as weathering products. We already assess their distribution on the façade by the on-site hyperspectral analysis.

SIMULATION OF FUTURE SCENARIOS

FUTURE

- These results are the bases for decay simulations and load simulation according to the IPCC future scenarios.
- Damaging simulation is a very useful tool to predict degradation in cultural heritage buildings that allows to plan in advance maintenance or restoration actions.

Thank you!



chiara.coletti@unipd.it

Follow the Hyperion Project here: https://www.hyperion-project.eu/, https://www.facebook.com/HyperionEUProject/, https://youtu.be/07-1L8Stu9w

Deterioration of the West and East façades of Santa Maria di Servi (Venice) have been studied using photogrammetry and the resulting point cloud was managed in CloudCompare software. In order to determine the degradation patterns of the bricks, cross sections of the façades were extracted from the cloud adopting a 1 m step distance. In this way, 24 sections for the western façade and 16 for the eastern one were acquired. Descriptive coordinates of a selection of representative profiles were exported as coordinates and plotted in cumulative scatter diagrams

The first step consists on defining a Unified Climatic Parameter (UPC), which is a linear combination of the climatic parameters affecting the degradation process of a certain building material.

$$UPC = \sum_{i=1}^{n} a_i cp_i \quad (1)$$

being a_i the weighting coefficients for a particular building material and for a particular degradation parameter.

Three climatic parameters are going to be used: freeze-thaw days per year, relative humidity and peak hours of sunshine per day

Future steps:

Load resistence in riuns…

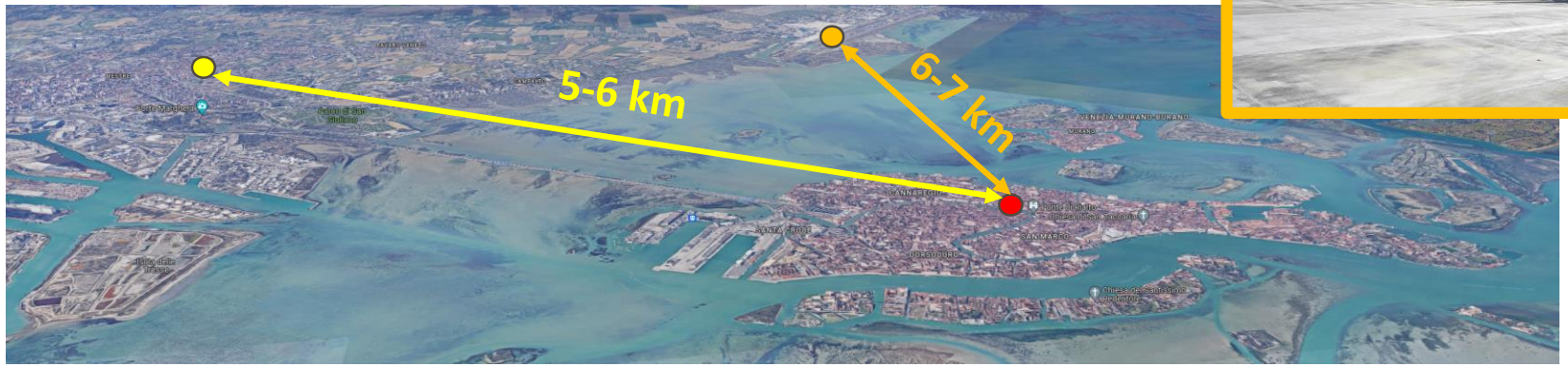
Do carmo Church, Portugal

Abbazia di Beauport, France

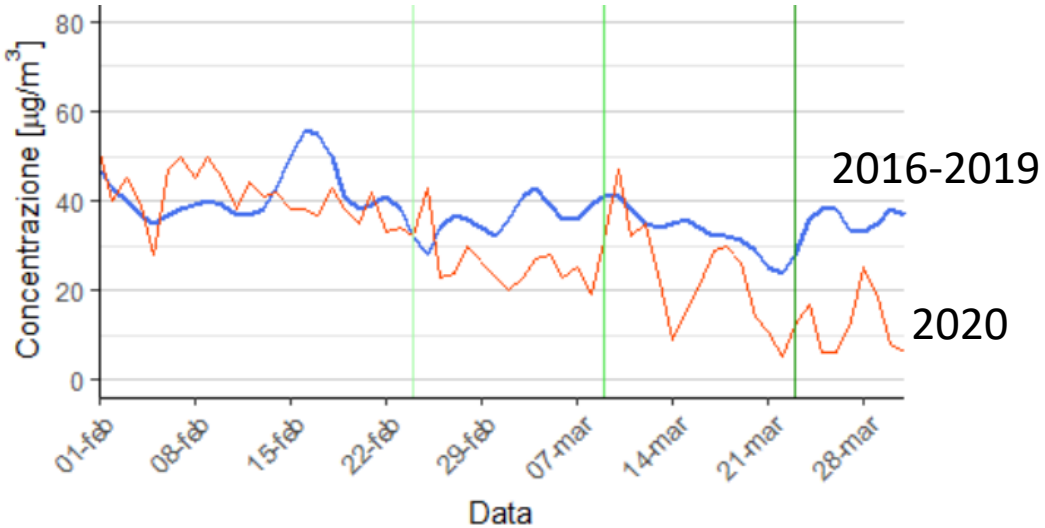
Abbazia di San Galgano, Italy

The **AIR QUALITY** in the municipal area is connected to the presence of a **PLURALITY OF EMISSION SOURCES** (production activities, urban and extra-urban traffic, port activities, heating, airport), to the climatic and morphological characteristics that affect the accumulation and dispersion phenomena of pollutants.

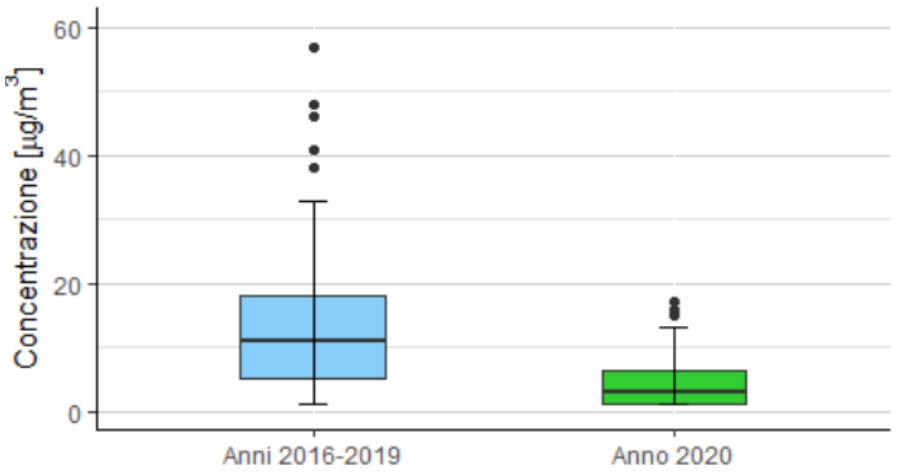
Marco Polo Airport, VE



Porto Marghera, VE



Trend of daily nitrogen dioxide concentrations in the two months of February-March: comparison between the four-year period 2016-2019 (blue line) and the year 2020 (red line)

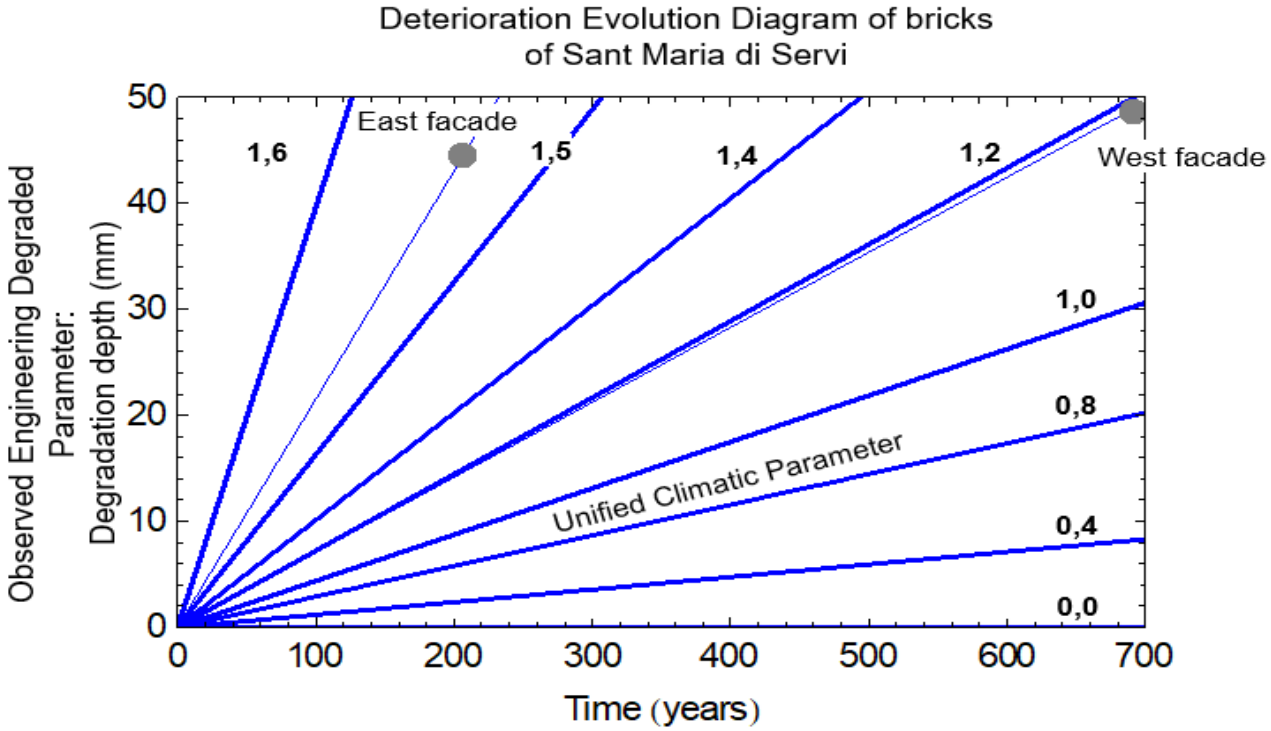


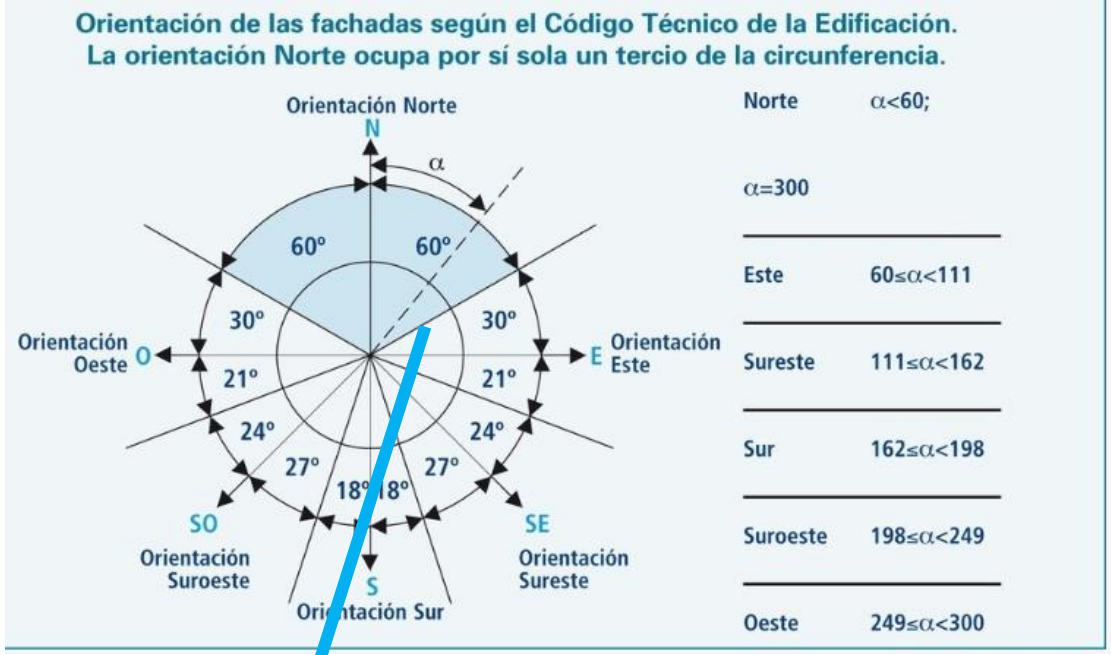
Distribution of daily nitrogen monoxide concentrations: comparison between the four-year period 2016-2019 (blue box plot) and the year 2020 (green box plot)

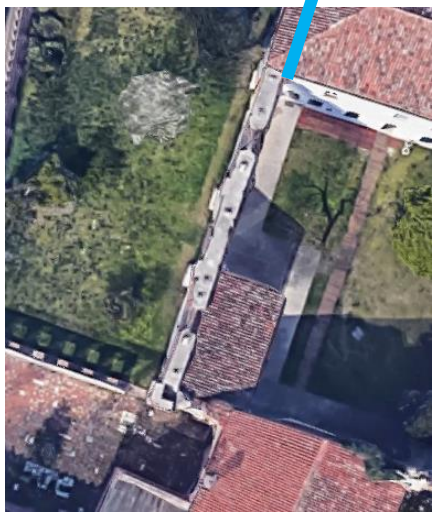
ARPAV (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto)

THE HYBRID DETERIORATION EVOLUTION DIAGRAM

The upper part of both sides of Section 3 are compared to obtain a second equation of the recession

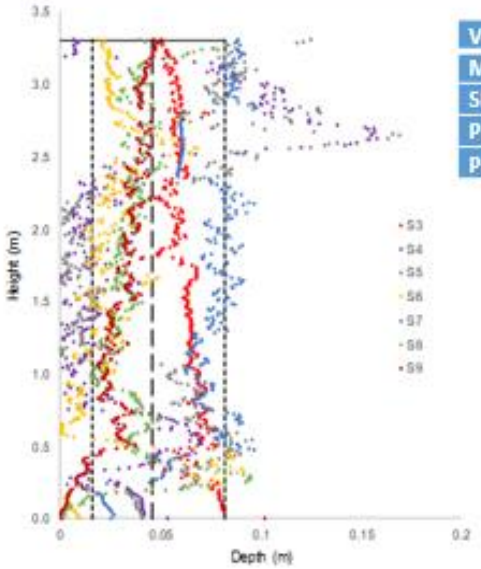




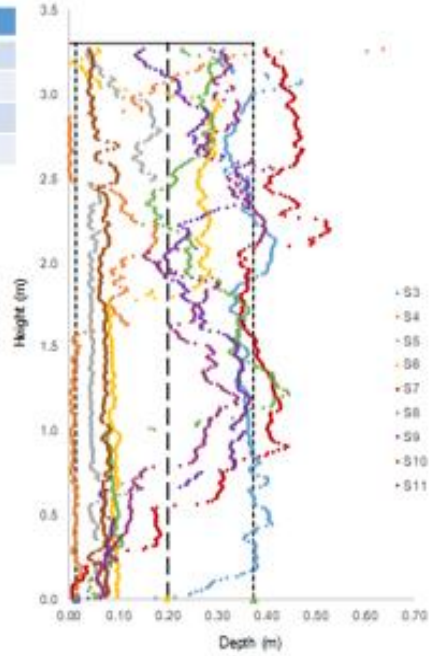


The difference between both sides along the selected part on the top of section S3 is 4.375 mm

Mean degradation in the west and east facades



Values in meters	Front	Back
Mean degradation	0.046	0.201
SD	0.027	0.137
P_5	0.016	0.016
P_{95}	0.082	0.375



Accounting for that the east façade has 1.81 peak hours of sunshine per day, while the west façade has 1.49 hours [21], assuming a constant recession and given that the difference between the depth of degradation at both sides of the façade is 4.375 mm (Figure 12), it can be concluded that:

$$4.375 = 692 \cdot \xi \, \mathrm{Tan}[0.000734\, n_{fdy} + 0.0497\, RH + a_3\, 1.49]$$
$$- 207 \cdot \xi \, \mathrm{Tan}[0.000734\, n_{fdy} + 0.0497\, RH + a_3\, 1.81]$$

$$OEPD = 0.0265 \cdot t \cdot \mathrm{Tan}[UPC]$$
$$UPC = 0.000734 n_{fdy} + 0.0494 RH + 0.7750\, n_{psh}$$

In the last twenty years Venice has presented a mean relative humidity (RH) of 69.1% and 4 frost days (n_{fd}). So, solving Equations 8 and 9 for n_{fty}=4 and RH=0.691, results in ξ=0.0265 and a_3=0.775.
Once the UPC is obtained, the recession depth corresponding to Santa Maria di Servi as a function of time is given by: