D4.4 Deterioration of the building materials under extreme events required in the CH vulnerability assessment

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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified, as referred to in Commission Decision 2001/844/EC

Modifications Index	
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ACRONYMS AND ABBREVIATIONS

CC	Climate Change
CH	Cultural Heritage
CIE	Commission Internationale de l'Éclairage
SfM	Structure-from-Motion
SWIR	Short Wave InfraRed
XRPD	X ray powder diffraction
3D	Three dimensional

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Executive Summary

Cultural Heritage is today suffering under the pressure of the economic growth that triggers hazardous habits. Extreme weather events are one of the many aspects of climate change having a dramatic impact on historical areas. The evidence of this large-scale human impact needs quantification of the current effects and prevision of the future ones, modelling the possible risk scenarios. The valorisation of the historical urban texture by the cooperation between research and governance is the win-win solution to fix new planning tools and achieve multiple goals for a sustainable transformation of the cities and more resilient systems for the future generations. To this purpose, this part of the HYPERION research (D4.4) is addressed to the quantification of the tangible effects of extreme weather events on the urban context, in order to define the hazard situation and support authorities for good practises in the challenge of Cultural Heritage preservation.

D4.4 focuses on the influence of extreme events on the decay and vulnerability of historical stone and brick buildings in Venice (Italy), a place that perfectly represents the fragile equilibrium between the mankind, its heritage, and the environment. Two pilot areas were selected as the main cornerstone for the field and laboratory investigations: the Clock Tower in St. Mark's square and the church of Santa Maria dei Servi (Tier 1 and Tier 2 building, respectively); further investigations were done on carved decorations in St. Mark's square and the church La Salute. Photogrammetric surveys, performed both on land (with a tripod) and in air (with a drone) allowed for providing 3D models, helping the detection and high-resolution study of the weathering patterns. Hyperspectral analyses, done both on field (with a drone) and in the laboratory, supported the mapping of the building materials, their collocation, and the spectral signature of their unaltered and altered composition. Finally, X-ray diffraction and colorimetric analyses in the laboratory provided complementary information about composition and surface features. The relevant results aim at detailing the climate change risk posed to coastal and lagoon environments, involving the wetting and salt weathering of building materials, due to or exacerbated by extreme floods, sea level rise, storms, coastal erosion, etc.

1. Introduction

1.1 Integration in the Hyperion's framework

This deliverable D4.4 collects the main findings of an investigation of the effects of extreme weather events on cultural heritage centred on the decay and vulnerability of historical stone and brick buildings in Venice, Italy. Most of the field and laboratory work was arranged by or done at UNIPD; however, D4.4 benefitted also from the collaboration of other Hyperion partners, namely IUAV, UGR, and OSLOMET. The deliverable D4.4 has a biunivocal relation with Task 4.4 of Work Package (WP) 4. It also have direct and indirect links with other WP4 deliverables. The direct connection is with the data reported in the deliverables D4.1 (edited by IUAV) and D4.2 (edited by UNIPD), about the Tier 1 building in Venice and the properties of selected stone and bricks used as building materials. The indirect connection is with the deliverables D4.3 and D4.5 (both edited by UNIPD), which support D4.4 in providing a multidirectional perspective on the weathering of building materials caused by environmental stresses.

The relevant data on the past (reconstructed) or present (measured) decay are to be integrated in the models created within HYPERION for quantifying also the future decay, and assessing the vulnerability of cultural heritage and the climate change risk (especially related to the impact of extreme events, e.g., floods, coastal storms, strong winds, etc.). These models are part of the Hygro-Thermal (HT) and Structural-Geotechnical (SG) simulation tools, in the framework of the Holistic Risk Assessment Platform (HRAP), addressed to heritage stakeholders.

1.2 Background

Since climate change is becoming an increasing problem, heritage monuments located in the urban context are considered as a sensitive and vulnerable element of the city (Gandini et al., 2018; Vidal et al., 2019). Although acid rain and the deterioration rate of historic buildings are long-known phenomena (Camuffo, 1992; Camuffo & Enzi, 1995), monuments have reached alarming levels during the last 100 years in which anthropogenic activity had a great impact on the environment (https://climate.nasa.gov/). The combined action between natural weathering agents (rainfall, fog, snow) and atmospheric pollutants (derived by the anthropogenic activity) drastically affects the material-atmosphere interface causing acceleration in the loss of the aesthetic quality of materials (Fassina, 2010; Casti et al. 2017).

All these factors of change are correlated and mutually empowered unleashing extreme events. This is one of the most important challenge of our days, strictly connected with the anthropogenic action and for which we are called to take measures to save the society, the economy, and the Cultural Heritage.

This deliverable (D4.4) is aimed to quantify climate change and the extreme events effects at a monument scale, in order to define the main causes of decay and support SG modelling and HT simulations for mitigation actions.

1.2.1 The case of Venice (Italy)

Global warming have been continuously increasing in the last century (https://climate.nasa.gov/; IPCC 2014) and is now indisputable that it is triggering significant changes in macroscopic characters of the climate system causing snow and ice cover reduction, changes in precipitation regime, sea level rise (Reimann et al. 2018), and increase of floods frequency.

In November 2019, the city of Venice was hit by a tide as high as 187 cm. It was the worst flooding event in Venice since 1966, when the city was hit by a tide of up to 194 cm (76 inches), according to government statistics. Data from historical series of flooding since the year 1860 (historical archive: https://www.comune.venezia.it) unequivocally show that extreme events are progressively increasing (Fig. 1)[3].

Moreover, buildings in Venice (as in many other cities developed along the coastline) are affected by salt crystallization that in this specific case, considering the effects of sea level rise, is becoming the main damage factor. Indeed, the historical basements made of Istria stone (compact limestone) are often submerged and the brick walls (highly porous) are exposed to water capillary rise, that in a lagoon environment causes aloclastism and differential decay (Figs. 2 a, b and c). Moreover, monuments in Venice clearly display other typical decay forms, such as black crusts (Fig. 2d) and biological growth and fouling in the intertidal zone (Fig. 2e).

[3] The MOSE project for the protection of the Venetian Lagoon from being submerged by the Adriatic Sea from flooding have been finally started to be operational during October 2020.

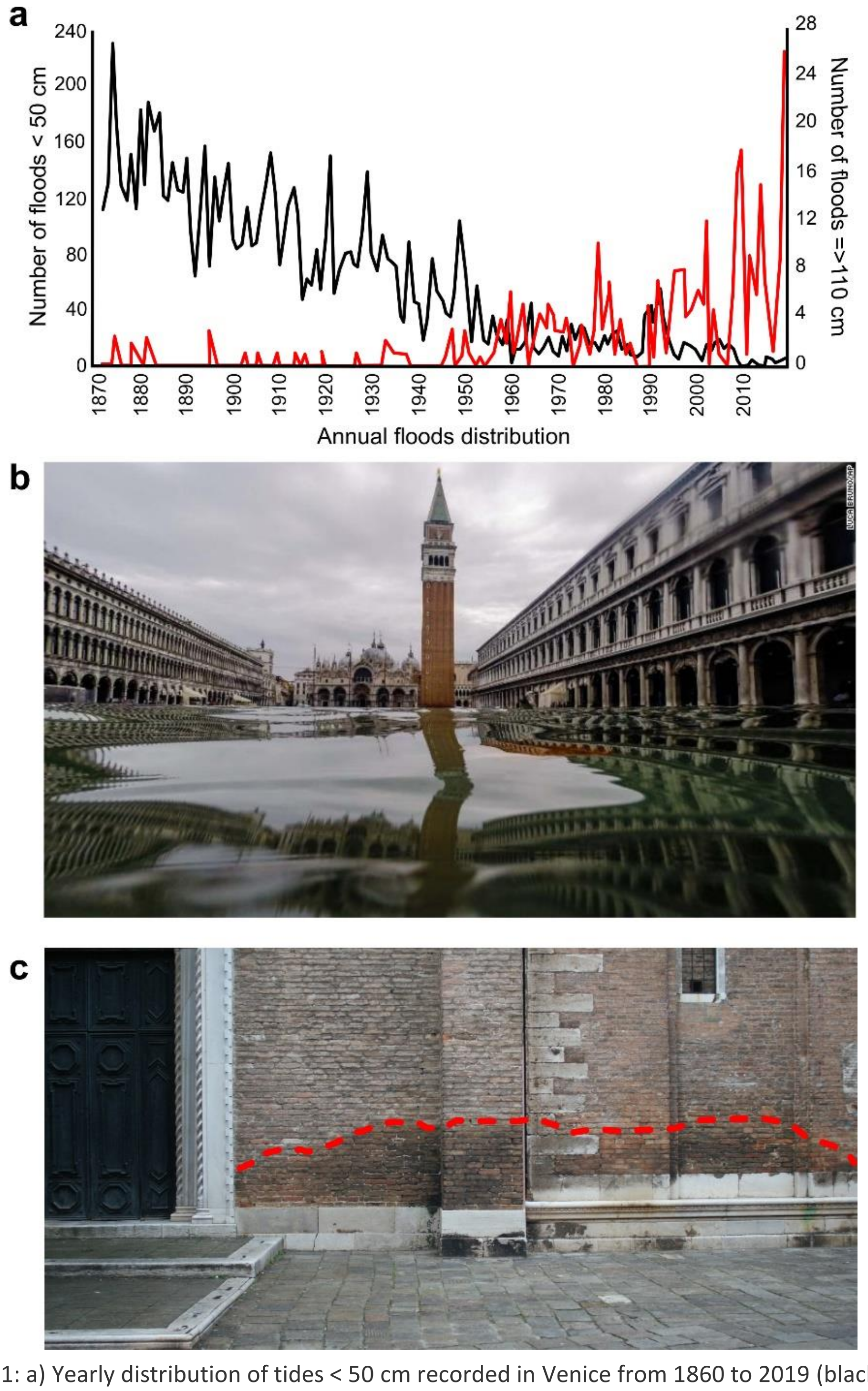
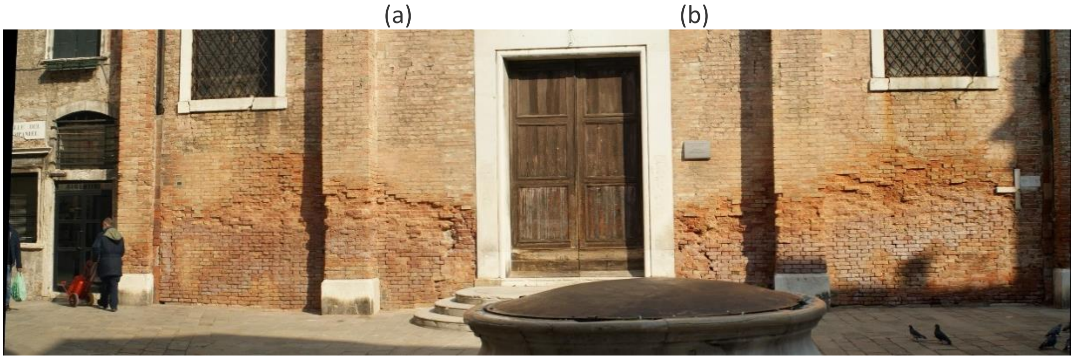


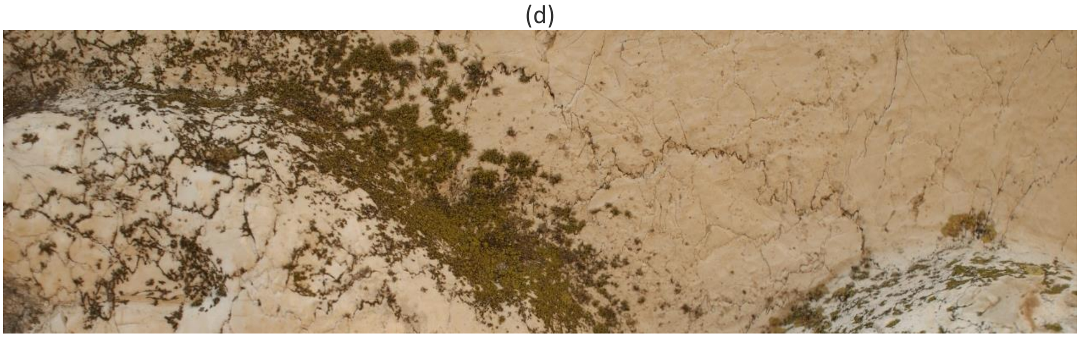
Figure 1: a) Yearly distribution of tides < 50 cm recorded in Venice from 1860 to 2019 (black line); Yearly distribution of tides > 110 cm recorded in Venice in the same period (red line); b) Photo by Luca Bruno/AP for CNN, https://edition.cnn.com/2019/11/13. A flooded St. Mark's Square is seen on Friday, November 15, in Venice, Italy. c) external wall of the façade of the Basilica di Santa Maria Gloriosa dei Frari in Venice, some days after the high tide (at the beginning of December 2019): the red dotted line shows the presence of water/humidity in the walls several days later the tide.


(a) (b)



(c)

(d)



(e)

Figure 2: a, b and c) effect of capillarity rise and salt crystallization; d) black crusts; f) detail of biological decay on stones.

1.3 Purpose and scope

1.3.1 A risk-based approach

Risk-based approaches should incorporate an assessment of sensitiveness and of adaptation capacity. Vulnerability is often assessed on a large scale (e.g. regional, local) and buildings, in particular historical ones, are not considered. The management of Cultural Heritage requires a new approach, which considers all the elements and buildings as part of the urban environment (Gandini et al, 2017). Climate change and geo-hazards are increasing the potential impact on historic areas, in terms of maintenance of hosting Cultural Heritage sites and monuments (De la Fuente et al., 2013; Di Turo et al., 2016; De Marco et al., 2017).

Main challenges are: i) the understanding and the quantification of climate change effects, in short- and long-term and from local to regional scale, and ii) the development of sustainable mitigation plans for the urban renewal.

1.3.2 The selected cases of study in the city of Venice

In order to study the main decay processes on CH in the Venetian Lagoon different building and decorative elements were selected.

In particular the study was focus on (see Fig. 3):

1) Tier 1 building: the Clock Tower in Saint Mark's Square: it has been selected because directly exposed to the action of sea sprays in Saint Mark Square, the heart if the city. It represents one of the pilot sites, were a microclimate monitoring network has been set up.
2) Tier 2 building: the Santa Maria dei Servi Church in Cannareggio: it is mainly brick made. It has been selected for the high differential decay observed on the main facade and the high degree of material deterioration due to salt crystallization and capillarity rise.
3) The basement of the columns in the Saint Mark's Square and the angels of the staircase of Madonna della Salute bridge (*Punta della Dogana*, in front of the Saint Mark's Square): all these decorative elements have been selected for their continuous exposure to seawater tides and sea spray.

This approach guarantees to cover different scale levels (building scale and detail scale), different environmental conditions, and different materials (e.g. different types of stones and bricks) mainly used in Venice.

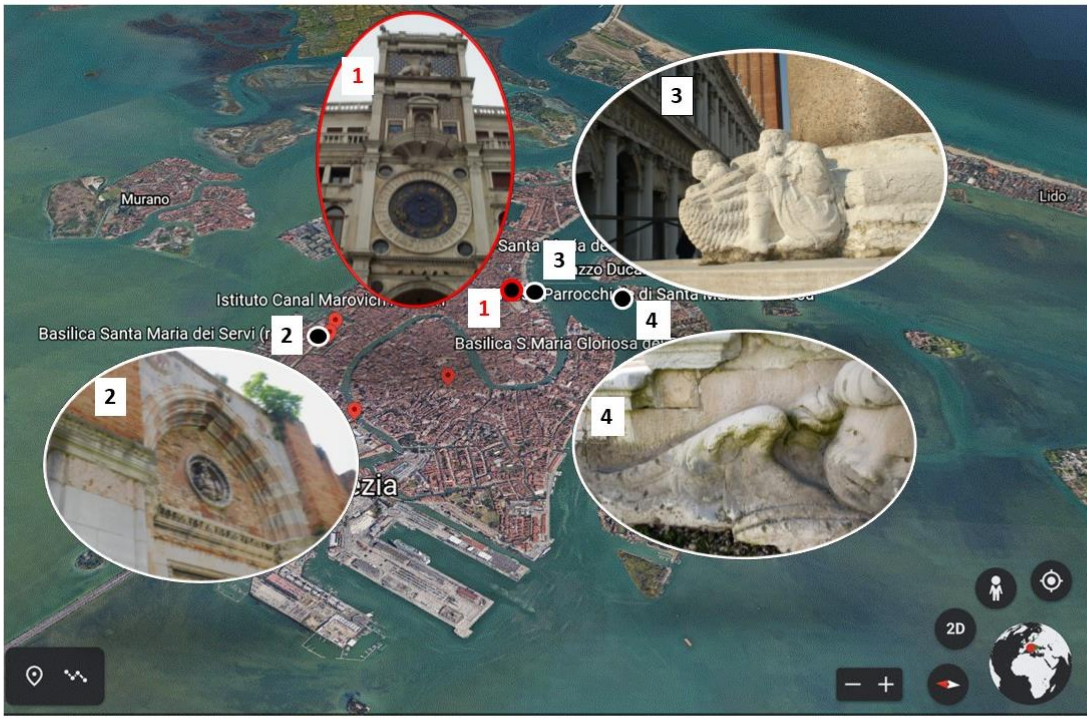


Figure 3: The selected cases of study in Venice. In red: Tier 1 building, the Clock Tower in Saint Mark's Square; in white: the Tier 2 buildings: the Santa Maria dei Servi Church in Canneregio (on the left); the basement of the column in Saint Mark's Square; and the decorative angles on the stair of the Madonna della Salute Church (on the right).

1.4 Approach

1.4.1 Analytic methodology

For the study of the Tier 1 and 2 buildings and the characterization of stones and bricks and their deterioration products, a series of analytical approaches (on-site and in the laboratory) were adopted. They are schematically represented in Figure 4, and briefly described in the following paragraphs.

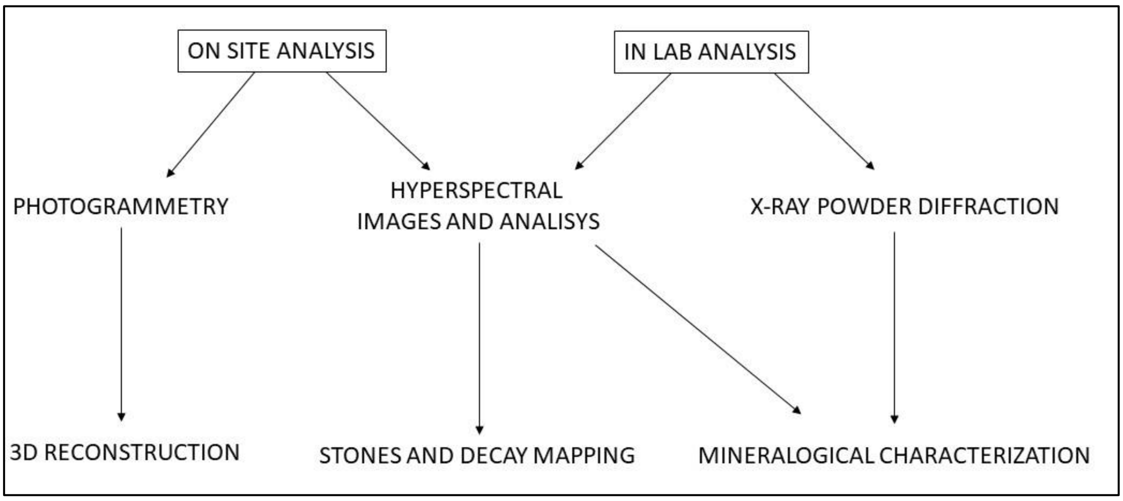


Figure 4: Flux scheme of the methodological approach used in the D4.4.

Photogrammetry

The photogrammetric survey allowed performing a complete 3D photogrammetric reconstruction using structure-from-motion (SfM) approach using drone and tripod (10 m).
The survey was carried out on:
- the main façade of the Clock Tower in Venice (Tier 1)
- on the main façade, the secondary façade, and the apse of the Santa Maria dei Servi in Venice (Tier 2);
- on other specific case studies (e.g. columnar base, bas-relief) in order to properly study the main effect on the stone surface due to the salt crystallization, water rise and biological growth.

Hyperspectral analysis

Hyperspectral analyses have been used both in laboratory and on the field. Laboratory analyses are useful to create a database of the spectral signature of the unaltered building materials. In addition, hyperspectral data have been acquired also on samples, which underwent artificial weathering during laboratory experiments (*e.g.* salt crystallization or exposure to atmospheric conditions), in order to have data on the possible effects of specific environmental stressors on the different materials and to identify the diagnostic absorption bands.

Laboratory analyses have been done with the Headwall Photonics Nano-Hyperspec and Micro-Hyperspec cameras. These hyperspectral cameras work in the VNIR range (400-1000 nm) and in the SWIR range (Short Wave InfraRed, 900-2500 nm) respectively. The Nano-hyperspec camera has a total of 270 spectral bands, 640 pixels per slit and the spatial resolution used in our laboratory setup was around 0.15 mm. The Micro-hyperspec camera has a total of 166 spectral bands, 384 pixels per slit and the spatial resolution used in laboratory was around 0.35 mm.

The survey at the Clock Tower was done with the Nano-Hyperspec camera using a drone (DJI matrice 600 M600 pro) performing two different vertical flights. One flight has a spatial resolution of 4.3 mm per pixel, in order to have detailed data, and a second flight with a spatial resolution of 1 cm that gives an overall idea of the composition and weathering products distribution. The spectral range of the analyses is the VNIR (Visible-Near InfraRed), but additional data in the SWIR (Short Wave InfraRed) are planned.

X-Ray powder diffraction (XRPD)

X-ray powder diffraction (XRPD) was applied to identify the mineral phases. Diffraction data were acquired on a PANalytical X'Pert PRO diffractometer, operating in Bragg-Brentano reflection geometry with CuKα radiation, 40 kV of voltage and 40 mA of filament current, equipped with an X’Celerator detector. Qualitative analysis of diffraction data was carried out with X'Pert HighScore Plus® software (PANalytical) and the PDF-2 database.

Spectrophotometry

The color of dried and wet fired bricks was assayed on a 3nh spectrophotometer according to the CIELab system, which describes color as lightness (L*: -100 = black, +100 = white) and adds the two chromatic coordinates a* and b*, which reflect the amount of red-green and yellow-blue colors (a*: -60 = green, +60 = red; b*: -60 = blue, +60 = yellow), respectively. The degree of color difference (ΔE*) was calculated according to the following equation:

$$\Delta E = \sqrt{({L^*}_2 - {L^*}_1)^2 + ({a^*}_2 - {a^*}_1)^2 + ({b^*}_2 - {b^*}_1)^2}$$

where subscript '1' refers to measurements on dry samples and subscript '2' on wet ones. Measurements were carried out under a CIE standard illuminant D65 (simulating daylight with a color temperature of 6504 K) with SCI/SCE modes and wavelengths between 400 and 700 nm.

2. Results

2.1 The Clock Tower (Venice)_Tier 1

The Clock Tower (Tier 1 building in Venice, 15th century) is located on the northern side of St. Mark's square.

2.1 1 On site photogrammetric survey

In Figure 5 is reported the photogrammetric reconstruction of the Clock Tower obtained by drone flights.

Figure 5: Photogrammetry of Clock Tower in Venice

2.1.2 Architectural projections/sections for HT simulator tools

Beyond the knowledge on measurable parameters influencing degradation rate (D4.1 and D4.2), we supported OLSOMET partner for the recovery of architectural projections of the monument (Fig. 6, provided by the Municipality of Venice) and the production of architectural sections of the walls through measurements at specific locations (Fig. 7). This type of information is essential when running HT simulation tools (Task 4.6), because wall stratigraphy influences vapor circulation and thermal diffusion.

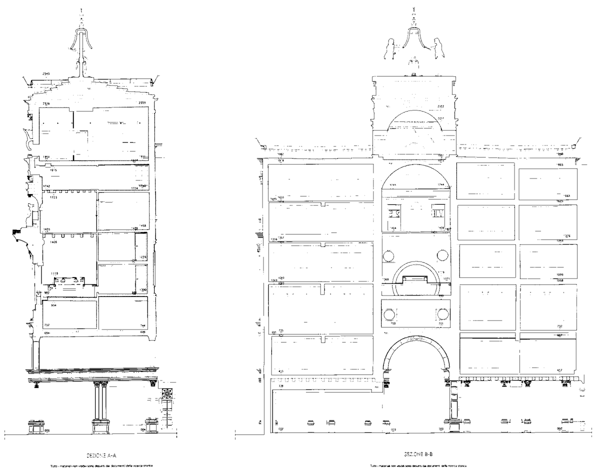


Figure 6: Architectural projections of the monuments (from Municipality of Venice documents)

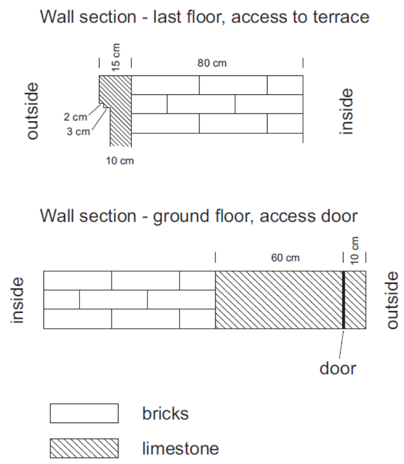


Figure 7: Architectural sections of the wall (from survey)

2.1.3 Hyperspectral analyses

In the VNIR laboratory analyses on the unaltered building materials (*i.e.* limestones) no diagnostic absorption bands were present in the spectra. On the contrary, on the Clock Tower we found two main bands at around 450 nm and around 700 nm (Fig. 9) related to weathering or due to the pigments.

The 450 nm band indicates the presence of Fe or other metals (*e.g.* Pb, Zn, Ni, Cu) oxy-hydroxides, likely derived by pollution (Barca et al. 2014), and are present on the entire façade of the Clock Tower (Fig. 8). The 700 nm band is instead more concentrated in specific spots. This band might represent biodeterioration, however the band shape of biodeterioration is different (Fig. 15). In the case of the Clock Tower the 700 nm band indicates weathering products of Cu (Fig. 9). In figure 9C is shown the map of Cu weathering products, which are not only found on the bronze statue but these products seemed to be transported by water in the lower portions under the statue. No spectral sign of biodeterioration have been found. However, the chlorophyll absorption band might be obliterated by the width and depth of the 700 nm Cu one. In addition, the blue pigments derived from minerals like sodalite also produce a 700 nm band. This is congruent with the distribution of the 700 nm band depth, which is higher and more concentrated in the inner part of the clock (left side of Fig. 8) and on the blue portions (right side of Fig. 8).

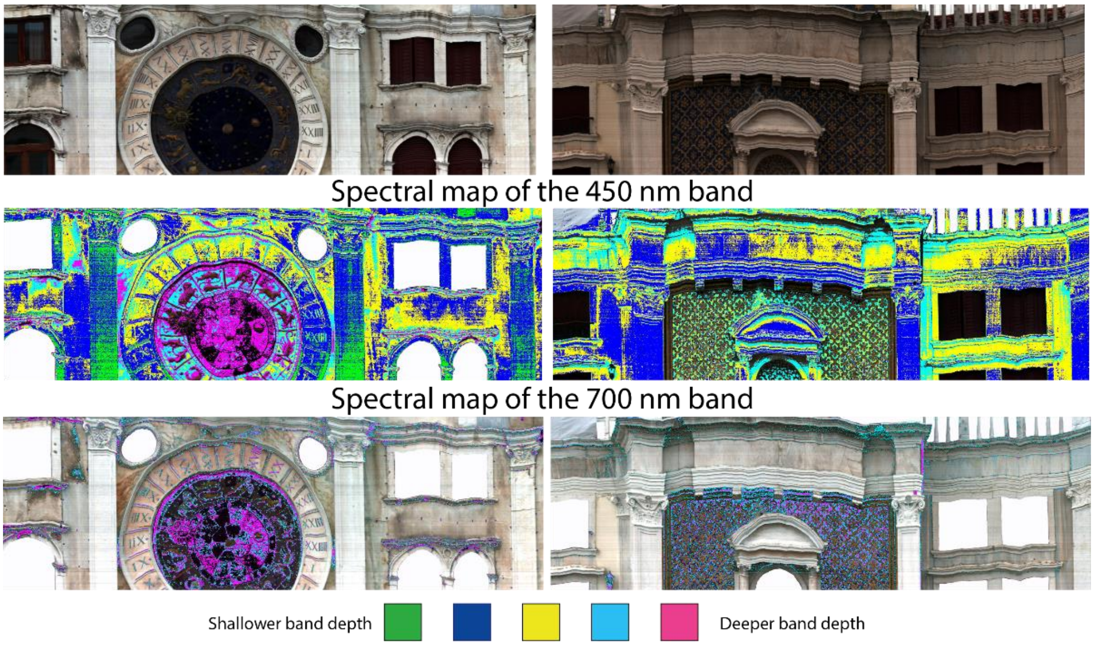


Figure 8: Hyperspectral maps of two main portions of the Clock Tower. The top images report the original acquisitions. The false colours in the other images indicate the band depth, and thus the abundance of the related compound, for two different wavelengths. Band depth increases from green (lowest values), blue, yellow, cyan and purple (highest values) respectively.

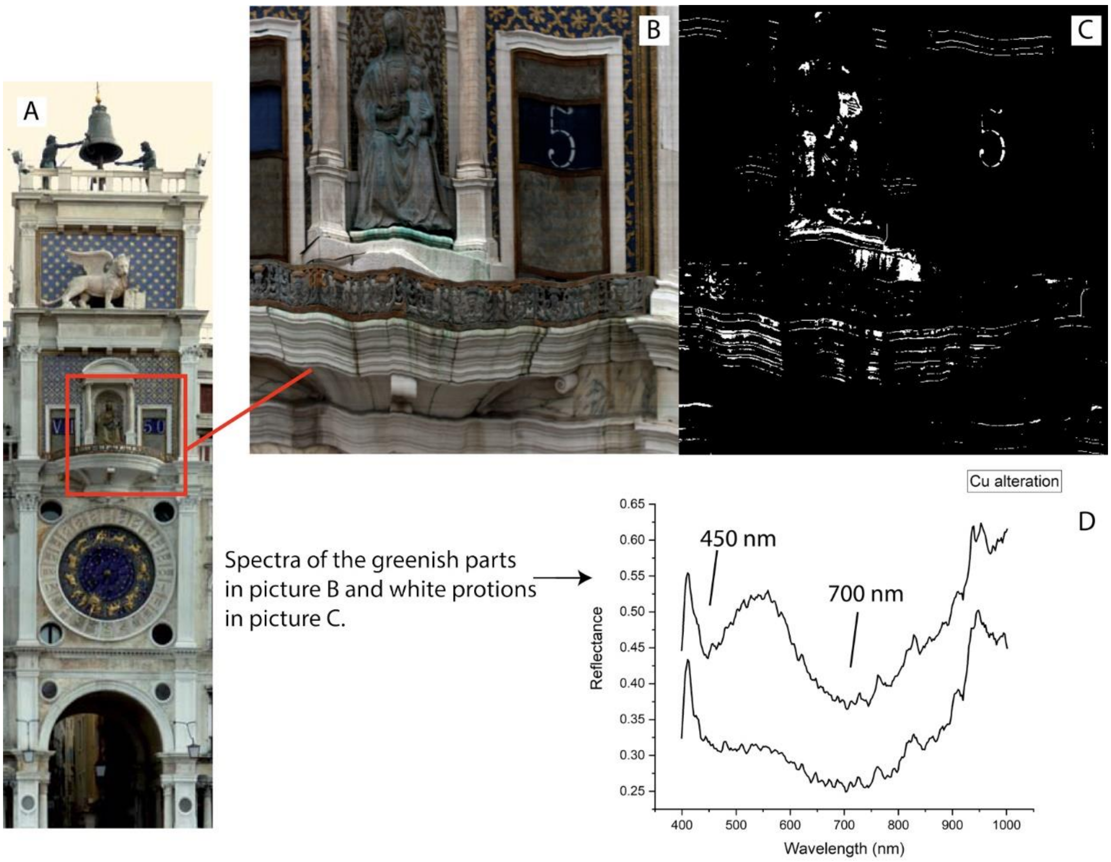


Figure 9: Spectral map of the 700 nm band on the highlighted portion of the Clock Tower. White areas in figure C indicates the presence of the 700 nm and thus of the Cu weathering products.

2.2 The Santa Maria dei Servi Church (Venice)_Tier 2

The Church of Santa Maria dei Servi (built in 1330 and partially demolished in 1815), is a Tier 2 building (Venice). It was selected to study the differential material loss in relation to the properties of the bricks, model the recession rate, and evaluate the effect of differential material loss on the technical properties of the damaged walls.

The main causes of decay identified for this building are: salt crystallization, water rise, and biological colonization.
The ruins are mainly affected by black crusts, detachments and loss of material, with different characteristics depending on the material type (e.g. stone or brick), and biocolonization with moss and secondary plants growth (Figs. 10a-f).


(a)


(b)


(c)


(d)


(e)


(f)

Figure 10: a, b) details of the Santa Maria dei Servi façade in Venice; c) damaged brick mansory; d) black crust on stones gate; e) stone (red verona marble) esfoliation; f) fractures and slab displacement caused by secondary plants.

2.2.1 On-site sample collection

Samples (bricks and mortars/grouts) were collected from the main façade (Fig. 11) to analyze mineralogy and decay (XRPD, POM, SEM-BSE and hyperspectral analysis).

Figure 11: Samples collection on the main façade.

Macroscopically, bricks are inhomogeneous (Squassina 2011) both in color (from red to yellow/green) and texture (fine homogenous texture, mixed layered and with clay agglomerates) (Fig. 12). Mortars/grouts also display differences from place to place, with evidence of modern interventions.

Figure 12: Samples (23 bricks and 4 mortars/grouts) collected from the main façade of the Santa Maria dei Servi.

2.2.3 Colorimetry in dry and wet condition

Color changes in dry and wet samples were measured in order to verify esthetical variations in different microclimate conditions, and the possibility to monitor the effect of the rain, the presence and permanence of humidity by image analysis. All samples show to be sensitive to color changes after wetting: in general, a* and b* components (yellow-red and blue-green, respectively) increase (Fig. 13) and L* (lightness) decreases (Fig. 14). All the color changes are outside the limit of perceptibility, defined as a $\Delta E \geq 3$ in the CIELAB color space (Benavente et al. 2002; Grossi et al. 2007), and therefore visible to the naked eye.

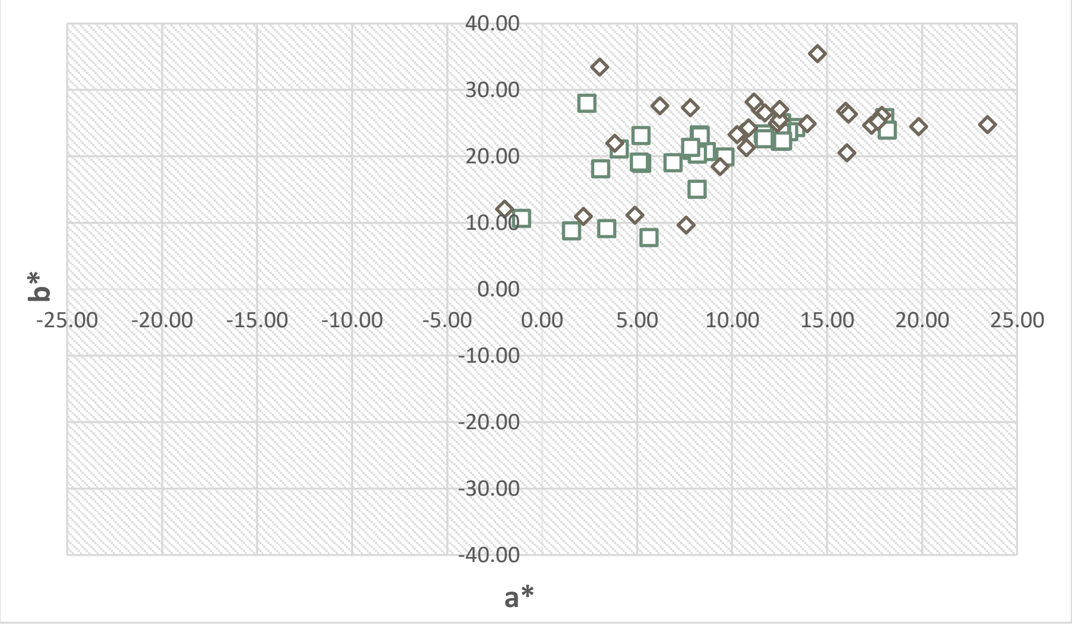


Figure 13: Colour coordinates, a*, b* measured in dry (square) and wet (diamond) conditions.

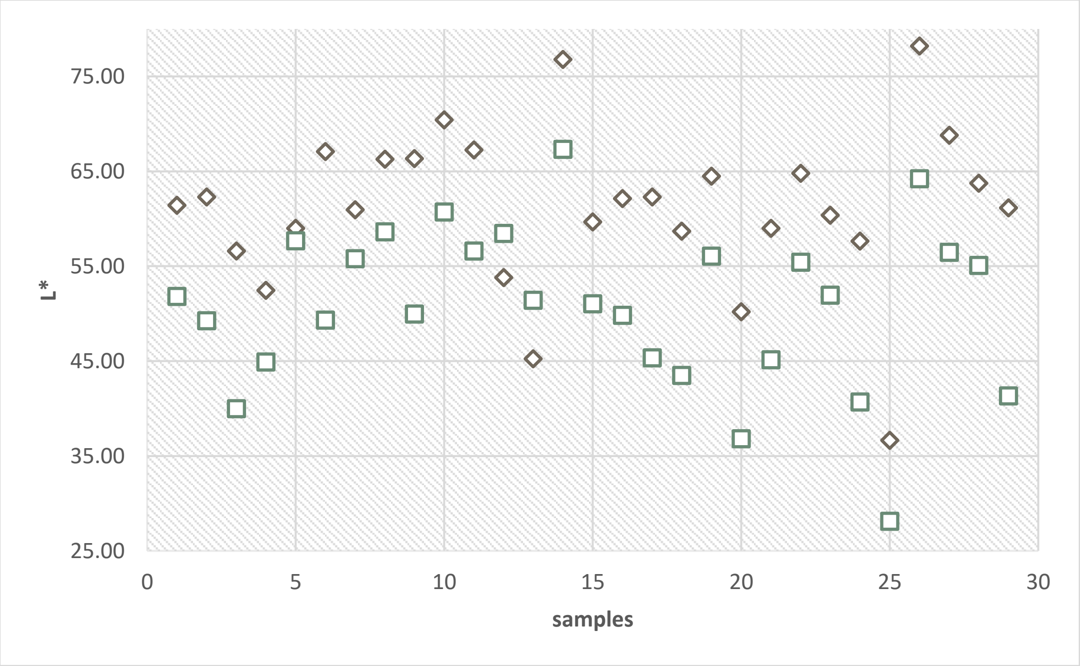


Figure 14: L* measured in dry (square) and wet (diamond) conditions.

2.2.4 Mineralogical characterization

2.2.4.1 X-ray powder diffraction analysis

All the 23 bricks and the 3 mortars/grouts collected on the façade of Santa Maria dei Servi were analyzed.

The XRPD analysis performed on bricks show a relative abundance of primary minerals (i.e. calcite and dolomite) and secondary firing minerals (i.e. diopside and gehlenite) suggesting a certain homogeneity in raw materials used. Indeed, the presence of carbonates and new Ca- and Mg- silicate phases provide indications on the different temperatures reached during firing (Fig. 15). Diopside and gehlenite occur at firing temperatures above 800 °C (Cultrone et al. 2001), while peaks calcite, dolomite and illite indicate that temperature does not exceed the 750-800 °C (Maritan et al. 2006). The consistence in the chemistry against the poor homogeneity in the mineralogical evolution of the mentioned phases suggested the absence of a good standardization in the firing process. This supports the idea that in the XII century there was a first phase of local production of bricks using local clay of the lagoon and without standardization in the quality of the final products (Squassina 2011).

Gypsum and mirabilite are often present in the bulk. 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).

Mortars collected on the walls are probably derived from recent interventions. All samples differ in their aesthetic aspect (suggesting different phases of application) but are all similar under the mineralogical point of view, being calcium-magnesium rich mortars with a silicate component (presence of quartz and illite).

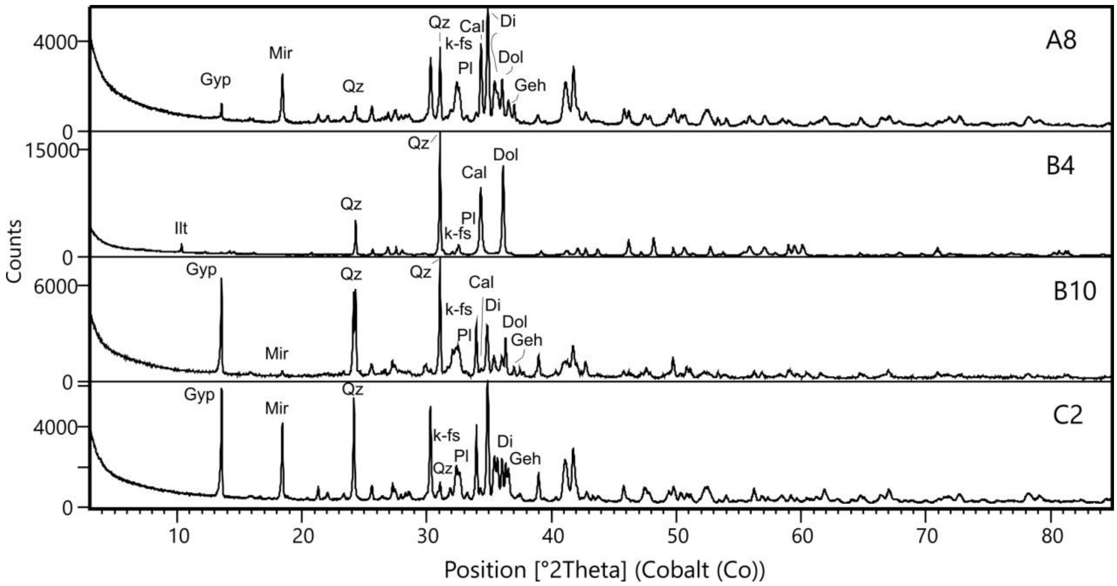


Figure 15: Representative XRDP patterns of brick samples (A8, B10 and C2) and mortars (sample B4). Mineral abbreviations after Whitney and Evans (2010): Qz = quartz; Ill = illite; K-fs = K-felspar; Pl = Plagioclase; Cal = calcite; Dol = dolomite; Hem = Hematite; Di = diopside; Geh = gehlenite; Gyp = gypsum; Mir = mirabilite.

2.2.4.2 Hyperspectral analysis

Hyperspectral analyses on the bricks of Santa Maria dei Servi in Venice have been performed in the laboratory on the same samples also used for the XRPD characterization. Hyperspectral on-site analyses are also planned, and will be performed as soon as the tripod will be delivered (delay is due to Covid-19 pandemic).

In the SWIR spectra of samples subjected to laboratory salt crystallization experiments we found that the 1750-1760 nm band, typical of sulphates, appears on their salt-rich portions (Fig. 16). Therefore, we set that band as diagnostic to search for salts on the building materials. As expected, spectral maps of the 1760 nm band on the Santa Maria dei Servi bricks highlighted areas rich in salts (Fig. 17). The spectra of these areas display additional bands compared to the laboratory experiments, in particular the triplet between 1400-1500 nm typically associated to hydrous sulphates (e.g. gypsum, bassanite, mirabilite). This is in agreement with the XRDP analyses, which confirm the presence of gypsum and mirabilite in the bricks.

In the VNIR range the most indicative band is the one related to chlorophyll, whose band centre is at around 680 nm. As shown in figure 15C-D, we mapped this feature on a Costozza tile exposed to atmospheric weathering. This band is a tracer of biodeterioration and has been also found on the B11 sample (Fig. 18 A-B). Unfortunately, the 680 nm band on the B11 sample is located in thin greenish veins, whose 680 nm band depth is not enough for a precise mapping.

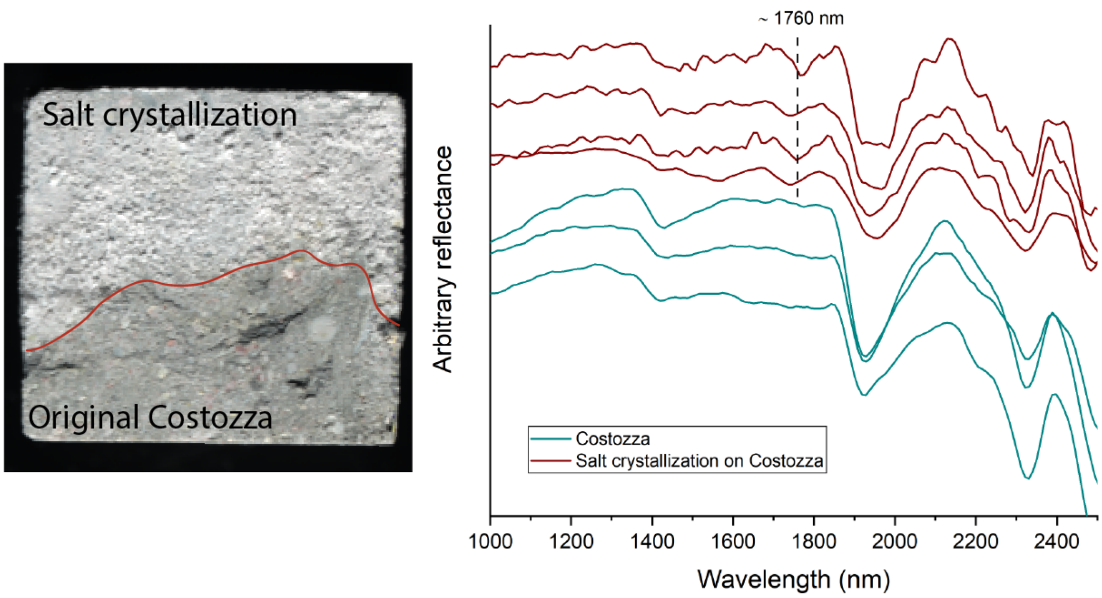


Figure 16. Costozza stone used for salt crystallization experiments. Spectra of the unweathered parts of Costozza show the typical limestone spectra with the water absorption bands at 1400 nm and 1900 nm and the CO_3 absorption at 2300 nm. Spectra of the Salt rich side there is the 1760 nm characteristic of sulphates (in this case sodium sulphate decahydrate $H_{20}Na_2O_{14}S$).

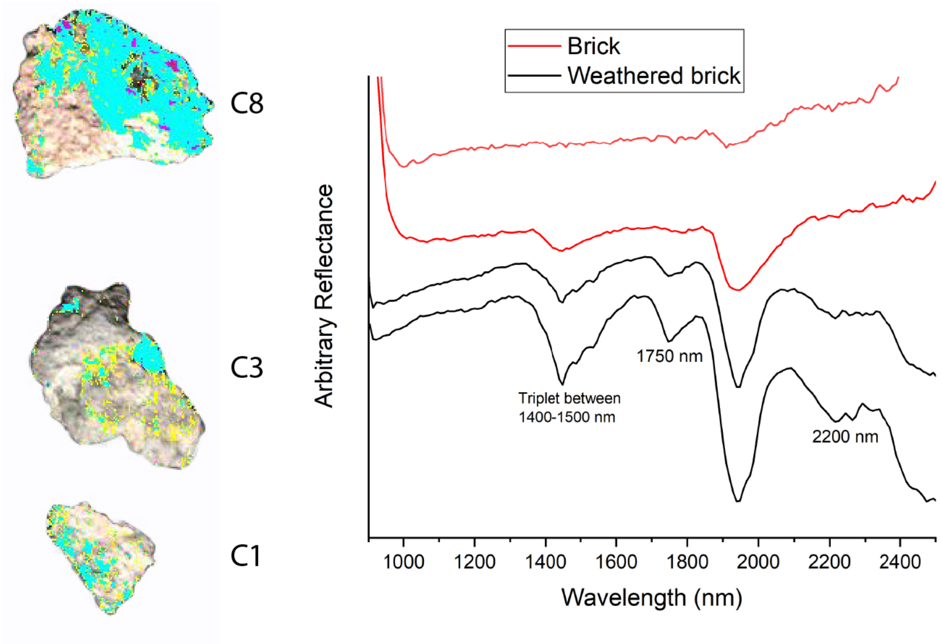


Figure 17. Spectral map of the 1750 nm band on the C8, C3 and C1 brick samples. Band depth is lower in the yellow areas, increases in the cyan areas and reaches the maximum in the purple portions. In the spectra of the weathered bricks there are many features of the sulphates spectra, absent in the original spectra. These bands are the triplet between 1400-1500 nm, the 1750 nm and the 2200 nm band.

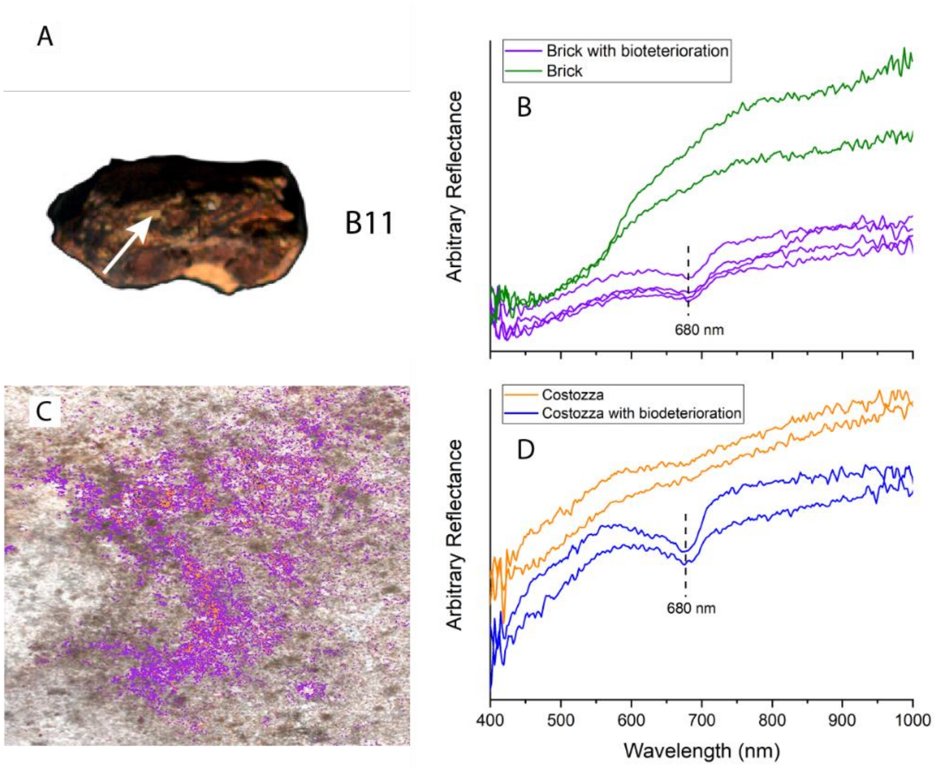


Figure 18. A) B11 brick sample from Santa Maria dei Servi, white arrow indicates a greenish vein where spectra indicates the presence of biodeterioration. B) Spectra of the brick with and without biodeterioration. C-D) Biodeterioration on a Costozza tile marked by the 680 nm band. In this case the band depth was sufficiently pronounced to allow the mapping of the feature on the tile (band depth increases from purple to orange).

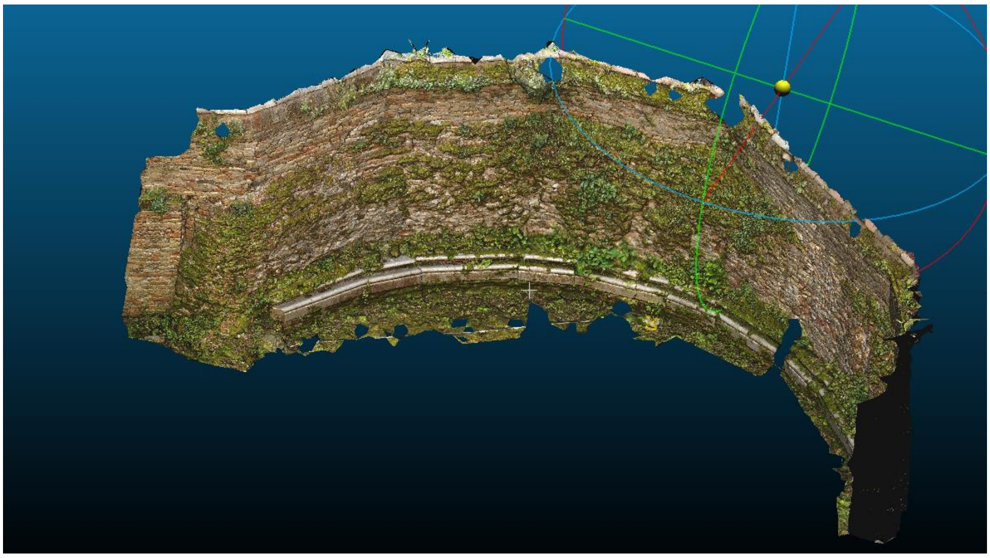
2.2.7 3D reconstruction

The photogrammetric survey of Santa Maria dei Servi (Figs. 19a-c) is a powerful tool in order to verify, observe and measure the differential decay of the brick masonry. It will be used for estimating the recession rate due to the environmental stressors and for preventing decay on other brick made buildings in the city of Venice.

It also allows to observe some structural characteristics, for examples the polygonal structure of the apse (Fig. 16), not visible by a traditional survey.

(a)

(b)



(c)

Figure 19: (a) main facade (east); (b) secondary façade (south); (c) apse.

2.2.8 Decay assessment

During the on-site survey and with the support of high 3D resolution images the decay assessment of the façade was performed. In Figure 20 are reported:

- the collected samples, layered in yellow;
- the main location of black crusts, layered in blue;
- the main location of biodeterioration (in particular secondary vegetation), layered parts in green.

Decay assessment is relevant to define the main causes and process of decay, as well as the distribution of their patterns on the façade. Vegetation grows mainly on the top of the façade; black crusts interest mainly elements made of carbonate rocks (see Fig. 10 a and d) and more complex architectural features (Fig. 10b).

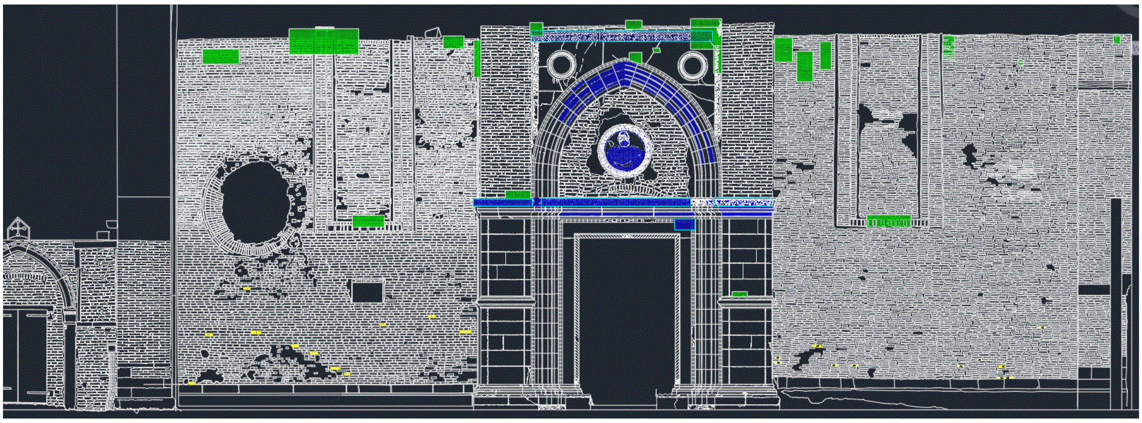
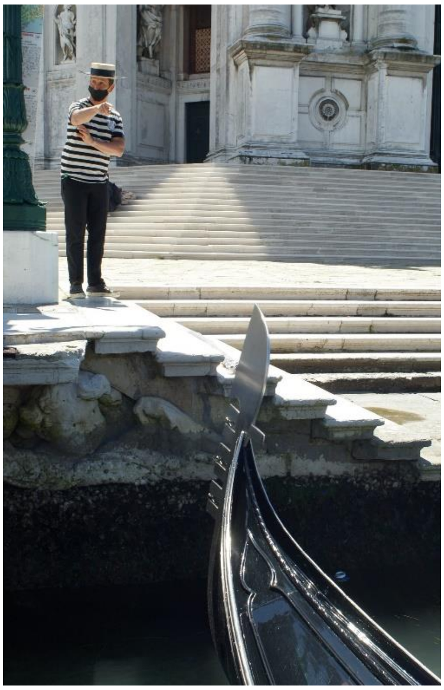


Figure 20: (a) main facade (east); (b) secondary façade (south); (c) apse.

2.3 Decorative elements and sea rise effects (Venice)

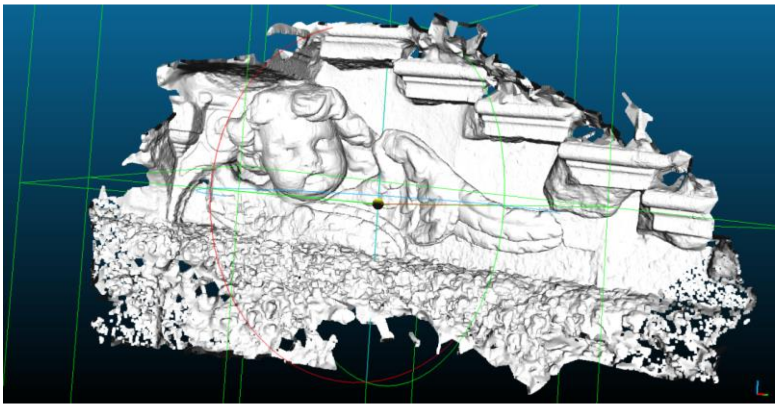
Some decorative elements were also selected to study the effects of the sea rise.

In figures 21a and b are reported the west and east angles of the staircase of Madonna della Salute. Figure 21c reports the photogrammetric reconstruction of its eastern side, while figs. 20 d and 20 f show some preliminary results on the roughness study of the statue. These images clearly reveal a significant increase of roughness towards the bottom due to a gradient of surface damage and to the presence of algae.

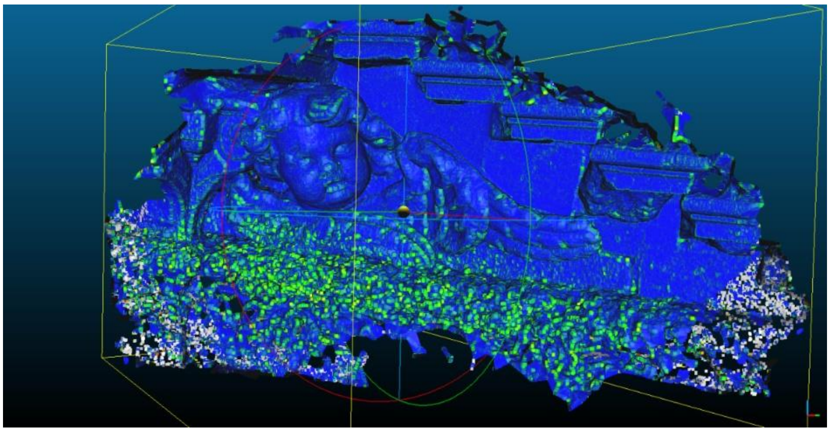


(a)

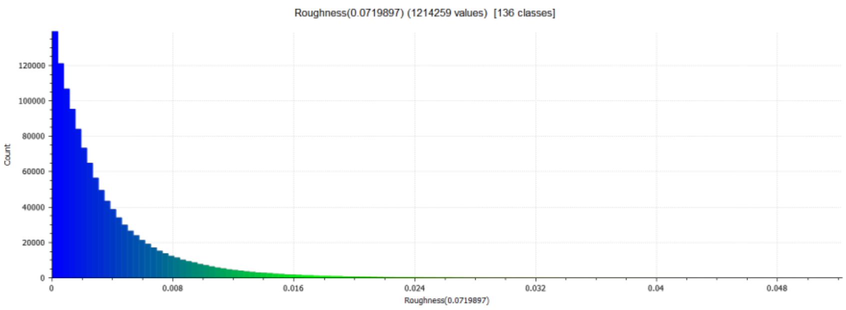
(b)



(c)



(d)



(f)

Figure 21: a) eastern side of the staircase of Madonna della Salute; b) western side of the staircase of Madonna della Salute; c) 3D reconstruction of the east angle; d) 3D reconstruction of the east angle in false colour for measuring roughness; f) preliminary results of roughness of the east angle (Fig. 16d).

3. Conclusions

The development of a critical thinking based on resilience represents a dynamic view for the future to build more sustainable systems balancing the cultural identity preservation and the adaptation to the current social requirements. Mitigation of climate change and adaptive resilience strategies need the support of politics and research. The quantification of the decay and the understanding of the main causes of decay are fundamental preliminary steps for guaranteeing the preservation of Cultural Heritage and historical urban landscapes.

Specifically, the present Deliverable (D4.4) aims to improve the ability of building materials decay prediction increasing efficiency and accuracy of predictive CH vulnerability assessment, implementing enhanced 3-D models and hyperspectral analysis in the Tier 1 (WP6) and Tier 2 (Santa Maria dei Servi Church) buildings.

Deterioration of physical and mechanical properties of the building materials (see D4.1 and D4.2) with decay experimentally determined under specific climate conditions (see D4.5), will improve structural/geotechnical simulations (SG simulators developed by OSLOMET in the frame of Task 5.2 and Task 8.5) and will be used for accurate prediction of structural safety risks, including CH vulnerability assessment of enhanced extreme events (such as floods, coastal storms, and wind events).

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