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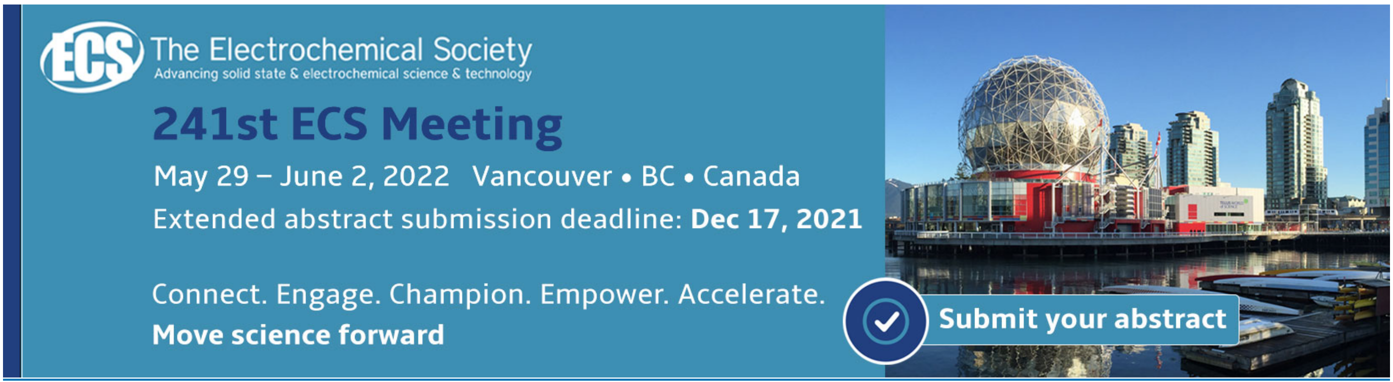

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Towards IoT monitoring of street-side monuments: the Florentine *Dietrofront* as a case study

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Abstract. The need for care often shown by ageing cultural heritage and the circumstantial lack of dedicated budget are increasingly calling for smart monitoring solutions to shift the maintenance paradigm from reactive-preventive to predictive. Monitoring artworks poses additional issues with respect to the more common industrial solutions, such as aesthetics, dealing with unusual materials, remote locations (archaeology), etc. In this scope, the "Dietrofront" statue in Florence, by artist Michelangelo Pistoletto, is an emblematic instance. Installed on a traffic roundabout, it comprises four travertine blocks, one of which hangs 5 m above the ground supported by a steel structure which has shown relevant symptoms of damage during the 2006 restoration works. During a later intervention, we seized the opportunity to equip the structure with a three IoT sensing devices, so as to monitor thermo-hygrometric conditions, inclination and vibrations of the structure. Various issues common to outdoor monuments have been faced, such as the need for visual non-intrusiveness and the unavailability of power supply. A small wireless sensor network was designed and installed, also exploiting an existing room inside the nearby mediaeval city gate. The network is fully solar-powered by photo-voltaic modules integrated on both the statue and the gate and not visible from the street. The data obtained have been analysed and compared to a simple lumped-parameters structural model, so as to estimate the relevance of traffic-induced vibration on the steel structure. The risk of water vapour condensation has also been assessed.

1. Introduction

It is not uncommon to find monuments installed on traffic roundabouts, often along with vegetation, and such situations should be understood as a whole as an artwork. Here, architectural and natural elements blend with the urban environment, and such coexistence relies on a balance between technical factors and cultural and social impact. Maintenance and interventions should be envisaged as a mean to preserve such equilibrium; since the physiological decay process, if not properly forecast and treated, may lead to a permanent damage affecting matter integrity and the overall readability of the artwork.

Decay phenomena belong to three broad categories: ageing, natural causes and human behaviour. Ageing relates to surfaces being constantly exposed to environmental agents (temperature, humidity, rainfall, wind and solar radiation) which, combined with urban pollution, can promote degradation [1, 2, 3]. Natural causes of decay include colonisation by biofilms, lichens, algae, and others [4, 5, 6]. Common sources of human-caused deterioration include vandalism, graffiti and traffic-induced vibrations; moreover, the studied monument has witnessed a peculiar episode: in 1998 a car crashed at high speed on the statue, damaging its base. Such contingency forced an emergency intervention to restore the structural safety of the structure.

Authorities in charge of safeguarding cultural heritage have long had a very narrow perspective, focusing only on the artefact, and this has often led to underestimating indirect damage. This narrow-focused approach was often exacerbated by a widespread lack of awareness in citizens and authorities of dealing with an actual artwork, often made by famous artists (the *Dietrofront*, by Michelangelo Pistoletto, is a striking example thereof). Furthermore, the lack of funding at a local level inhibited maintenance on artworks considered “of minor importance”, thus limiting the activity to spot interventions following contingencies which mined the structural safety of the work and put human safety at risk.

A rational, more efficient way to allocate maintenance resources necessarily relies on the definition of intervention thresholds related to measurable parameters. Where this is currently done, these steps are demanded to experts and performed during spot diagnostic campaigns, thus leading to high labour costs and to an inherently discontinuous monitoring. Conversely, the rapid spread of internet connectivity and the availability of low-cost sensors and micro-controllers offers a great opportunity in the scope of maintenance planning, paving the way for more aware and effective ways of preserving heritage. While Internet-of-Things (IoT) technologies are being widely deployed in the industry – driven by saving opportunities and public financing like the Industry 4.0 paradigm sponsored by the EU – the cultural heritage sector still relies on preventive (if not reactive) maintenance patterns. Hence inefficient resource allocation and, in some cases, heritage loss due to ineffective intervention. In this context, IoT devices may provide valuable real-time information on stress factors on the artwork, be it temperature, radiation, vibration, etc., hence enabling long-term stress logging, quick detection of anomalous situations and, when large volume of heterogeneous data will be available, the development of predictive algorithms.

In this paper, we present some early steps taken in this direction. The *Dietrofront* statue by Michelangelo Pistoletto in Florence, Italy, has been chosen as a case study and equipped with wireless sensors in order to monitor a number of parameters and to understand whether traffic-induced vibration and environmental conditions may affect structural stability and integrity. In Section 2 we describe the statue, its characteristics and the designed monitoring infrastructure. In Section 3 we present the obtained data and the inferred information.

2. Materials and methods

In this section, a brief outline of the history of the monument is given, and the statue and the designed monitoring infrastructure are described.

2.1. History of the statue

Michelangelo Pistoletto’s opus exhibits a great versatility in the choice of materials and art languages. During the 1980’s the artist used to carve small figures in expanded polyurethane which were later used as models for large-scale stone monuments, and the *Dietrofront* is no exception [7]. The idea of turning the model, carved in New York in 1981, into a larger artwork occurred while planning the large 1984 personal exhibition in the Forte Belvedere in Florence, Italy (Figure 1), and lead to the statue being manufactured by the craftspeople of the Nicoli art workshop in nearby Carrara [8]. After the exhibition, the statue was donated to the city administration (Comune di Firenze) and eventually placed where it currently stands, in front of one of the surviving city gates. In 2000, the Florentine artist Marino Vismara actively promoted a restoration work for the statue, which had been damaged and displaced by the 1998 car crash, eventually carried out by conservator Alberto Casciani. During such activity the travertine blocks were lifted by a crane in order to recover the original position and the statue was completely restored: surfaces were cleaned with an ammonium carbonate poultice, biological patinae were

Figure 1. Staging of the 1984 exhibition

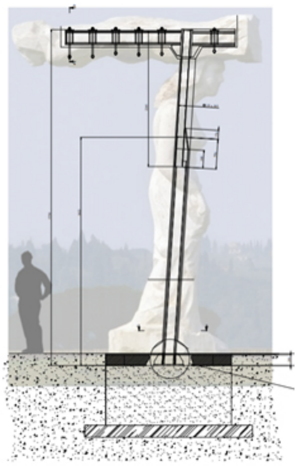


Figure 2. Steel structure

treated with biocide and damaged structural links were reinforced with stainless steel pivots and epoxy resin (Figure 3).

2.2. Description of the statue

The huge sculpture is carved out of four travertine blocks and stands on an underground concrete plinth. It displays two female figures, one standing and virtually supporting, on the head, the other, which lies in a horizontal position and protrudes towards the back. The vertical figure comprises three blocks: a 105-cm-high hollow base and two 4-m-high shells on top of it, which are joined along a vertical plane and constitute the torso and the head. The horizontal figure, which is also hollow, hangs from a steel structure concealed inside the lower figure, as shown in Figure 2. A supporting column is rigidly fixed in the foundation plinth, runs through the internal cavity of the vertical figure, and supports an horizontal beam on its to end. The bathtub-shaped travertine block constituting the horizontal figure hangs from the beam through 22 tie-rods. A fibreglass cover is used to complete and seal the horizontal figure on its top side. Overall, the surface shows a fairly rough texture, the marks due to machining being clearly visible, as is the glue used to seal the joints.

2.3. Design of the monitoring infrastructure

The monitoring infrastructure can be split in three main blocks, as shown in Figure 4: *i*) the *on-board sensors* are placed directly on the statue to measure the desired values and send the data on a wireless short-range connection to the *ii*) *local infrastructure*; this is connected to the web and transmits the collected data to the *iii*) *data server*, which stores them, processes them and makes them available for visualisation and processing.

Devices constituting the first two parts belong to the BeanAir 2.4GHz series, a commercial implementation which uses 2.4 GHz radio communication for the local data link. For what concerns the on-board sensors, three devices are used to quantify the impact on the steel structure of environmental conditions and vibrations:

- a **thermometer-hygrometer** (model ONE-TH) measures the environmental conditions inside the cavity;
- a **3-axial accelerometer** (model AX-3D) measures vibrations near the longest free end of the horizontal beam;
- an **inclinometer** (model INC) diagnoses possible long-term inclination drifts.

Figure 3. Phases of the 2000 major restoration

The sensors are mounted on a 5-mm-thick steel sheet which is fixed to horizontal beam near the extremity farthest away from the column, and lie inside the upper cavity of the statue, thus being protected against rainfall and solar radiation. Since the connection to the grid is not feasible, the devices are powered by a micro-photovoltaic (PV) installation comprising a 10 Wp solar panel, a 18 Ah lead-acid battery and a power regulator. Proper sizing of the power supply is crucial since non-powered sensors lead to missing data, impairing the subsequent processing. The PV panel is integrated in the fibreglass cover on the top of the statue, and has no visual impact on the artwork.

The local data infrastructure needs to be operated within a few hundred metres from the sensors to ensure proper coverage. Thanks to the collaboration of the city administration, an indoor space has been found inside the mediaeval city gate standing next to the roundabout (visible in Figure 3). Again, the lack of power grid connection has led to the design of a micro-PV

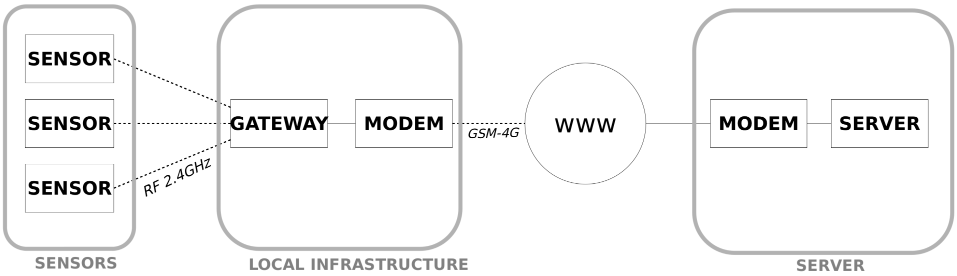


Figure 4. Block diagram of the monitoring infrastructure

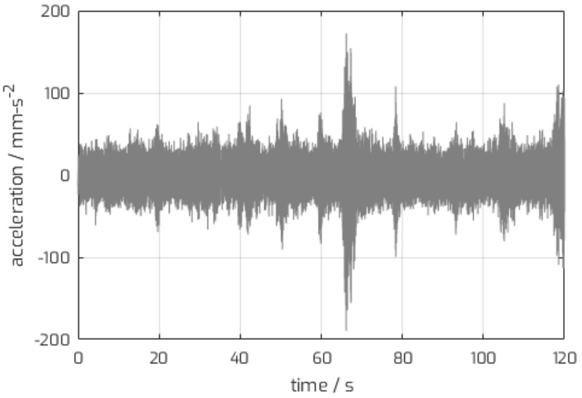


Figure 5. Data sample taken at 17:00

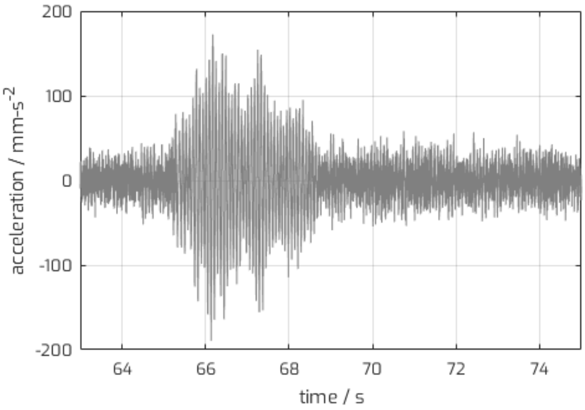


Figure 6. Zoom on single forcing event

installation similar to the one inside the statue (this time with a 30 Wp panel and two 12 Ah batteries in parallel). Such upscaling is needed because of the larger power needs of the mobile connection, since the proprietary data gateway communicates to the Internet via a 4G modem with a 5 W maximum power rating.

Again, data are finally received by a PC assigned a static IP address, as required by the commercial implementation, they a stored and made available for processing and visualisation.

3. Results

Data collection has started on February 2019. Some interruptions in the communication between the receiving PC and the local infrastructures have shown that the designed power harvesting solution for the gateway is not totally reliable, especially during several consecutive cloudy days in winter. Unfortunately, the solution found – installing the PV panels on a small east-facing opening in the walls on the city gate– is the only possible one not requiring special authorisations, since the building and the whole historical city centre are listed in the UNESCO World Heritage and undergo strict requirements on facades and roofs. Nevertheless, this poses only a partial problem, since data are stored in the sensors and transmitted to the PC via the gateway when the mobile connection is active. This means that real-time communication is not guaranteed but that data loss is avoided. In the following subsections, a first analysis of the collected data on vibration, inclination and environmental conditions is presented.

3.1. Vibrations

Due to battery constraints, data on vibration on three spatial axes are collected once per hour during a sampling time of 120 s, with an acquisition rate of 1 kS/s. Each sample accounts for 4 MB of data to be sent over the Internet. A sample taken at 17:00 during a workday is plotted in Figure 5. The data clearly show a number of vibration bursts with different magnitudes, likely due to different types of vehicles passing on the roundabout at different speeds. A zoom of one of the events is shown in Figure 6: the main vibration frequency is clearly visible, and the damping time can be estimated in about 1 s.

To compare the overall vibration magnitude at different times of day, we chose the RMS value of acceleration along the z-axis as a measure of average stress during the 2-s sampling period (results for a workday are plotted in Figure 7). Such value shows a double-peaked pattern, with lower values during the night and two broad maxima in the morning and early afternoon. This is consistent with the vehicle flow rate patterns in cities, thus confirming the hypothesis of traffic being the main cause of vibration.

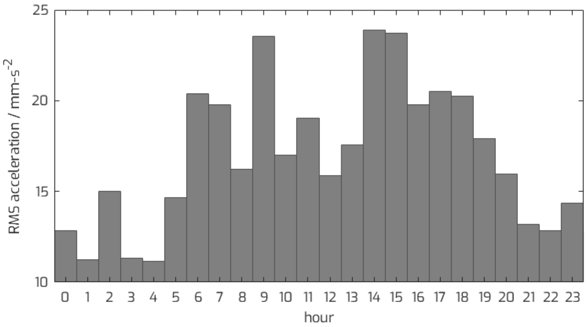


Figure 7. RMS acceleration during a workday

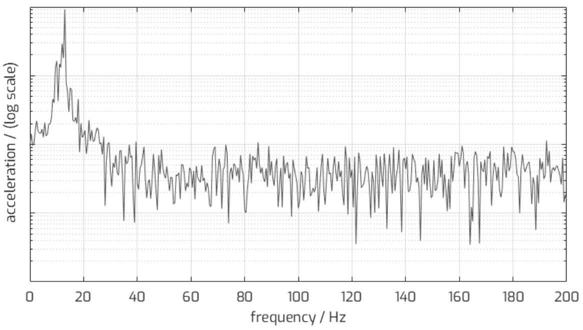


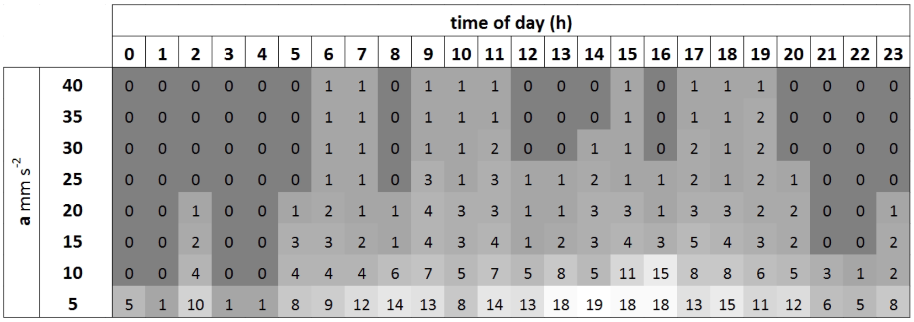
Figure 8. Spectral content of typical burst

As it was shown in Figure 5, vibration is not continuous but is amplified in isolated bursts. A simple statistic analysis was carried out in order to get a more significant representation. Considering a 1-s moving quadratic mean of the sample, peaks are counted which exceed given thresholds (5, 10, 15, 20, 25 and 30 mm/s^2). The results for the 24 considered samples are shown as a colour plot in Figure 9. Again, the double-peaked pattern is clearly visible.

For what concerns the spectral content of the measured vibration, FFT has been performed on various bursts selected from the recorded logs and the obtained results compared. All of them show the same pattern, similar to that reported in Figure 8. Only a major peak around 13 Hz is visible, suggesting that other resonance frequency of the ensemble lie outside the range of traffic-induced vibration (6 to 30 Hz, according to [9]).

3.2. Lumped dynamical model

A simple 2-D lumped-parameter dynamical model has been used to verify that the collected data are consistent with the characteristics of the statue. The lower part of the statue stands on the ground and does not contribute to supporting the upper part. The steel structure is modelled as three beams: two composing the vertical column and one for the horizontal beam. Namely, the beams used are standard HEB sections reinforced by welding metal flanges on the open sides, hence obtaining a "boxed" section. In a first, tentative model the upper stone block is represented as a point mass located at its centre of mass and associated with appropriate moments of inertia. Inertial data have been estimated by photogrammetry using a structure-from-motion (SFM) technique, then processing the obtained point cloud and estimating the material density in 2.6 ton/m^3. Such approach showed to oversimplify the behaviour and lacked to predict the measured resonance frequency at 13 Hz, only identifying the three eigenmodes at 1.2, 4.7



	time of day (h)																							
a mm s^{-2}	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
40	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	1	0	1	1	1	0	0	0	0
35	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	1	0	1	1	2	0	0	0	0
30	0	0	0	0	0	0	1	1	0	1	1	2	0	0	1	1	0	2	1	2	0	0	0	0
25	0	0	0	0	0	0	1	1	0	3	1	3	1	1	2	1	1	2	1	2	1	0	0	0
20	0	0	1	0	0	1	2	1	1	4	3	3	1	1	3	3	1	3	3	2	2	0	0	1
15	0	0	2	0	0	3	3	2	1	4	3	4	1	2	3	4	3	5	4	3	2	0	0	2
10	0	0	4	0	0	4	4	4	6	7	5	7	5	8	5	11	15	8	8	6	5	3	1	2
5	5	1	10	1	1	8	9	12	14	13	8	14	13	18	19	18	18	13	15	11	12	6	5	8

Figure 9. Statistical distribution of burst magnitudes during the day

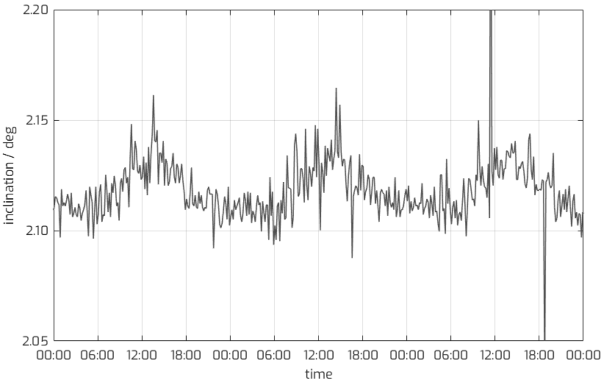


Figure 10. Inclination during 3 summer days

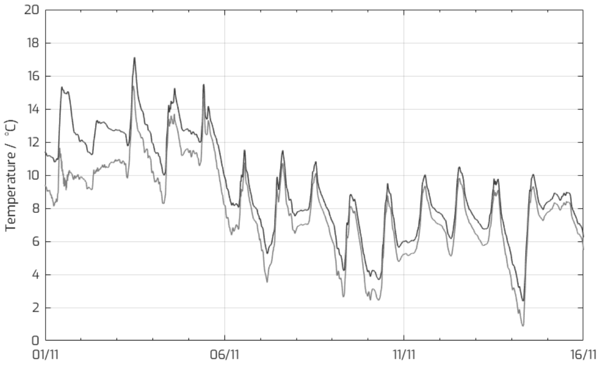


Figure 11. Temperatures during critical weeks

and 47 Hz (horizontal translation of the beam, rotation and vertical translation respectively). Subsequent improvements of the model have shown that the designed mechanical links between the statue and the structure play a fundamental role. In order to reduce stress in the stone, the block is suspended to vertical threaded rods by hinges. In turn, the threaded rods are connected to the supporting beam through Belleville washers. Together, the hinges and the washers provide an effective decoupling between beam dynamics and stone motion, especially at relatively high frequencies. A more detailed model, in which the hanging rods are modelled as springs and the linear mass of the beams is included, correctly predicts an eigenfrequency at about 12 Hz, corresponding to a rotation of the beam and to the mass staying still.

3.3. Beam inclination

Inclination has been measured every 60 s. The structure undergoes a slow oscillation during the day, likely due to temperature variations and thermal expansion. Such oscillations are clearly visible in Figure 10, in which data from three summer days are plotted. The amplitude is approximately 0.05°, corresponding to a displacement of some millimetres. This very small measured amplitude might be also due to some thermal strain of the supporting aluminium plate or to temperature effects on the sensing device.

In the long term, the sensors detect a very slow drift in inclination, whose rate amounts to approximately 0.08°/yr. This may be ascribed to a number of phenomena, among others: a drift in the device calibration, a slow plastic deformation of the structure and the concrete plinth slowly sinking in the ground. Further investigation is planned in order to understand the causes of such drift and their impact on safety and conservation.

3.4. Thermal data

Temperature and dew point have been measured every 10 min. Figure 11 shows air temperature and dew point during two weeks in November, which showed to be the most critical month (mainly due to the abundant rainfall). The difference between air temperature and dew point amounts to 1–2 K, showing that some moisture may condense on cold spots on the structure. On one hand, this suggests that more accurate measurement methods should be implemented – e.g., sensing the surface temperature rather than the air – if condensation risk is to be assessed; on the other hand, condensation risk is present only during a limited amount of time. In particular, data showed that the difference between air temperature and dew point is less that 1 K during approximately 600 h over the year. Moreover, due to the cavity being closed, radiating processes should equalise the temperatures of air, stone and metal, thus limiting condensation risk.

4. Conclusions

The spread of low cost IoT sensing solutions offers a great opportunity in the field of cultural heritage conservation, since it may improve resource allocation and, in the long term, it enables decay modelling and preventive maintenance scheduling. In this scope, a small monitoring infrastructure was implemented on an existing artwork to monitor environmental conditions and vibrations. The *Dietrofront* statue in Florence was equipped with three measuring devices for temperature-humidity, inclination and vibration, which transmit data to a local gateway located at approximately 50 m from the statue in the mediaeval city gate. In turn, the gateway relays the data to the web-connected remote server via a 4G modem. Since power mains are not available on the statue nor in the city gate, two micro-PV off-grid installations were required to harvest the energy needed by the devices, with rated powers of 10 and 30 Wp respectively. Visual impact was minimised by a thoughtful deployment of the PV panels. The system has proved effective, although the slight under-sizing of the PV in the city gate, due to visual impact constraints, does not allow continuous connection to the server, especially during several consecutive cloudy days. This does not impair data collection, since these are collected and stored in the sensing devices.

Data have been measured and stored for several months. A first analysis of the data has shown that *i*) there is some risk of moisture condensation on the steel structure, limited to a few weeks every year, *ii*) there appears to be a slight long-term permanent strain as measured by the inclinometer, estimated in less than $0.1°/\text{yr}$, *iii*) vibration of the structure is strongly correlated to traffic and occurs in isolated bursts; vibrations display a single relevant resonance frequency at approximately 13 Hz, the other eigenfrequencies not being excited by traffic. A simple lumped-parameters dynamical model has been implemented, and shows that the measured frequency is compatible with one of the eigenmodes, although more information on the geometry of the links between the structure and the travertine is needed for a more detailed modelling.

In general, this experience led to a some take-home messages for those wishing to face similar challenges: *i*) the number, type and location of installed sensors should be accurately planned, if possible using model-based approach to maximise the correlation between measured data and degradation patterns; *ii*) energy supply issues should not be overlooked, especially when the supply chain involves non-predictable sources such a solar or wind energy, and *iii*) Internet connectivity should be assessed in terms of available networks and reliability of links.

Overall, this activity is intended as a starting point towards the empowerment of real-time monitoring and predictive maintenance through IoT. In the current state, a number of technical improvement are still needed in order to make it a stand-alone, reliable tool. Nevertheless, projects like the one described play a key role in proving the technical and economic feasibility of IoT monitoring solutions in the field of cultural heritage, where often the different backgrounds of involved people – art historians, conservators, architects, scientists – and the deriving lack of communication inhibits the deployment of potentially beneficial projects.

Acknowledgments

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References

[1] Fassina V and Lazzarini L 1981 *Water Air Soil Pollut* **15** 343–52
[2] Fermo P, Goidanich S, Comite V, Toniolo L and Gulotta D 2018 Geosciences **8** 6 349
[3] Vidorni G et al. 2019 *Eur. Phys. J. Plus* **134** 439
[4] Caneva G, Nugari MP and Salvadori O 2009 *Plant Biology for Cultural Heritage: Biodeterioration and Conservation* (Los Angeles: Paul Getty Pubns)
[5] Singh S and Chand T 2012 *Env Sc Europe* **24** 1–13
[6] Crispim CA and Lagarde C 2005 *Micr Ecology* **49** 1–9
[7] 2000 *Tuscia electa: Verso l'immateriale* (Torino: Hopefulmonster)
[8] Argan GC et al. 1984 *Michelangelo Pistoletto a Forte di Belvedere* (Firenze: Electa)
[9] Hunaidi O and Tremblay M 1997 *Can. J. Civil Eng.* **24** 736–53