

1. Research activity (max 1.000 words)

The aim of my research is contributing to the preventive conservation of paper collections through the development of innovative procedures based on an effective combination of refined hygrothermal modelling and climate-induced risk assessment. To achieve this broader purpose, two specific objectives are pursued: 1) exploration of the capability of the software IDA ICE extended with the HMWall model in simulating the dynamics of heat and moisture exchanges within library storage facilities; 2) enhancement of the comprehension of the interactions between the indoor climate and the books by means of dose-response functions and spectroscopic techniques.

Library collections are frequently affected by deterioration processes due to the environmental conditions in which they are stored. The conservation of paper is strongly interrelated with the air relative humidity, as organic-hygroscopic materials act as buffers on humidity fluctuations while being vulnerable to moisture-induced damage. Microclimate monitoring over long-term periods, in combination with whole-building hygrothermal simulation, can provide a thorough characterisation of the indoor climate, thus becoming a compelling diagnostic and prognostic tool for the preventive conservation of cultural heritage. The hygroscopic behaviour of library collections can be modelled employing tools of the HAM-family (Heat, Air and Moisture), used to simulate the simultaneous 1-D heat and moisture transfers through porous envelope materials. The effect of the hygroscopic content of library facilities on the indoor environmental conditions is simulated coupling the HMWall model with the whole-building dynamic simulation software IDA ICE (Indoor Climate and Energy). In this project, the HMWall model is used for the first time to simulate the hygrothermal behaviour of paper collections modelled as a single wall made in paper. The degradation scenario linked to the indoor climate conditions experienced by the collections can then be estimated either performing measurements directly on the artifacts through non-invasive spectroscopic techniques or using dose-response functions for library materials.

The first year of my research focussed on an intensive training on IDA ICE in advanced mode, used for modelling the indoor climate of a historic building and for evaluating retrofit solutions compatible with conservation and able to reduce energy consumption and thermal discomfort. An investigation on the thermo-hygrometric conditions inside microclimate frames (i.e. special frames used in preventive conservation for the passive control of relative humidity) was useful to study, on a smaller scale, the thermo-hygrometric conditions established in environments holding large quantities of hygroscopic materials. Two library facilities located in Rome were chosen as case studies for the long-term microclimate monitoring campaigns: the Biblioteca Storica di Meteorologia at the historical complex of Collegio Romano and the vast storage facility of the Biblioteca Universitaria Alessandrina within the Sapienza university campus.

The second year was directed to studying the use of the HMWall model in the IDA ICE simulation environment for the investigation of the influence of moisture exchanges through paper collections. After the analysis of the preliminary indoor climate datasets registered in the case studies, the capability of the coupled HMWall-IDA ICE model to simulate the hygroscopic behaviour of paper was examined. Physical and hygrothermal properties of common types of paper in library and archives were collected and used to derive the hygrothermal curves describing their hygroscopic behaviour. A sensitivity analysis was performed to identify the most influencing parameters in the hygrothermal simulation of paper collections using the Elementary Effects method based on Morris random sampling. The second part of the year was dedicated to a detailed study on the application of dose-response functions for the understanding of the deterioration risks associated to the environmental conditions. A comprehensive methodology for the assessment of the climate-induced risks was developed based on limiting curves for the crystallization/dissolutions of deliquescent salts and for the biological proliferation in damp walls. For the specific needs of paper collections, the isochrones method (based on cellulose hydrolysis kinetics) was thoroughly investigated in view of the application to the environmental conditions in the case studies. In addition, non-invasive spectroscopic measurements on book covers were used as proxies of material deterioration. An experimental program following a 3-month schedule was set up for the monitoring of the fading/colour changes on the covers of the books exposed to solar radiation in the Alessandrina library repository. Colorimetric measurements were also performed on a target sample to derive an empirical dose-response function to evaluate the impact of solar exposure on coloured paper. Finally, as part of the research unit URO1-Sapienza (Scientific responsible Prof. Siani A.M.), I co-authored the publication of two Deliverables about the definition of protocols for deployment of sensor node devices in microclimate monitoring campaigns within the European project *CollectionCare: Innovative and affordable service for the Preventive Conservation monitoring of individual Cultural Artefacts during display, storage, handling and transport*.

The activities planned for the third year include the calibration and validation of the building models of the case-studies through the monitored data. A comparison will be conducted between the indoor climate simulated in a room where the collection is modelled either as an internal thermal mass or as an HMWall object with the hygrothermal properties of paper. Moreover, the assessment of the performance of the validated models will unlock the possibility to study retrofit solutions and to suggest conservation strategies within the monitored library facilities. A mobility period funded through the Sapienza grant for joint PhD research projects is programmed to the Jerzy Haber Institute of Catalysis of Krakow (Poland).

2. Research products

a) Publications (ISI journals)

- Verticchio, E., Frasca, F., Cornaro, C., & Siani, A. M. (2020). Investigation on the use of hygrothermal modelling for paper collections. *IOP Conference Series: Materials Science and Engineering*, 949(1), 012015.
- Frasca, F., Verticchio, E., Caratelli, A., Bertolin, C., Camuffo, D., Siani, A.M. (2020). A Comprehensive study of the microclimate-induced conservation risks in hypogeal sites. The mithraeum of the Baths of Caracalla (Rome) *Sensors*, 20(11), 3310.

- Verticchio, E., Frasca, F., Garcia-Diego, F. J., & Siani, A. M. (2019). Investigation on the Use of Passive Microclimate Frames in View of the Climate Change Scenario. *Climate*, 7(8), 98.
- Garcia-Diego, F. J., Verticchio, E., Beltrán, P., & Siani, A. M. (2016). Assessment of the minimum sampling frequency to avoid measurement redundancy in microclimate field surveys in museum buildings. *Sensors*, 16(8), 1291.

b) Publications (NON ISI journals)

- Frasca, F., Cornaro, C., Verticchio, E., Siani, A.M. (2019). Optimising Conservation of Artworks, Energy Performance and Thermal Comfort Combining Hygrothermal Dynamic Simulation and On-Site Measurements in Historic Buildings. BSA2019 Conference (2-4 September 2019)

c) Manuscripts (submitted, in press)

- Frasca, F., Verticchio, E., Cornaro, C., Siani, A.M. (2020). Performance assessment of hygrothermal modelling for diagnostics and conservation in an Italian historical church. *Building and Environment* (under review).
- D'Erme, C., Verticchio, E., Frasca, F., Caseri, W., Cornaro, C., Siani, A.M., Santarelli M.L. (2020). Preliminary study of the mechanical and hygrothermal performance of concrete reinforced with fibrillated cellulose. *NanoInnovation 2020 AIP Conference Proceedings* (submitted).

d) Abstracts

- Verticchio, E., Frasca, F., lafrate L., Siani, A.M. (2019). Preliminary study on the environmental conditions within a scientific historic library in Rome. INAF workshop "Preventive conservation in museum, libraries and archives" (Palermo, 16-18 October 2019).
- D'Erme, C., Verticchio, E., Frasca, F., Caseri, W., Cornaro, C., Siani, A.M., Santarelli M.L. (2020). Preliminary study of the mechanical and hygrothermal performance of concrete reinforced with nanofibrillated cellulose. NanoInnovation Conference (Rome, 13-15 September 2020).
- Verticchio, E., Frasca, F., lafrate L., Siani, A.M. (2021) La Biblioteca ex CREA-CMA al Collegio Romano: analisi critica delle condizioni ambientali al fine della conservazione del suo patrimonio librario. AISAM Third National Congress (L'Aquila, 9-12 February 2021).
- Frasca, F., Verticchio, E., Bile, A. , Fazio, E., Favero, G., Grinde, A., Siani, A.M. Definition of allowable targets from indoor climate observations in exhibition rooms: the case study of the Rosenborg Castle (Denmark). AISAM Third National Congress (L'Aquila, 9-12 February 2021).
- Mazzei, G., Frasca, F., Verticchio, E., Siani, A.M. Sperimentazione di uno strumento per la misura dell'umidità relativa in ambienti ad elevata umidità. AISAM Third National Congress (L'Aquila, 9-12 February 2021).