# A multi-scale modelling-experimental framework for predicting the chemo-mechanical degradation of paper

Amir Parsa Sadr , Siavash Maraghechi , Akke Suiker , and Emanuela Bosco*[1]

[1]Eindhoven University of Technology, Department of the Built Environment, Eindhoven – Netherlands

**Abstract**

This contribution presents a multi-scale modelling-experimental framework for predicting the chemo-mechanical degradation of paper (1). Paper is modelled as a two-dimensional periodic repetition of a fibrous network unit cell, where the fibres are characterized by a moisture-dependent chemo-hygro-elastic constitutive behaviour. Paper degradation occurs primarily due to the hydrolysis of cellulose, which causes a reduction of the degree of polymerization and a consequent decrease of the effective mechanical properties. This may ultimately lead to embrittlement and loss of material integrity. The proposed model accounts for the interplay between the acidity of the paper, the ambient environmental conditions, and degradation behaviour by first determining the coupled time evolution of the degree of polymerization, acidity, and moisture content. A time-dependent evolution law for the tensile strength of the paper depending on these parameters is proposed and calibrated from dedicated micro-tensile experiments (2,3). A change in moisture content induces internal stresses in the fibrous network, potentially leading to brittle damage once the fibre tensile strength is reached. The effective hygro-mechanical properties of the degrading fibrous network are calculated as a function of time using asymptotic homogenization. Numerical simulations highlight the impact of the time-evolving moisture content, acidity of the paper, and microstructural features on the degradation process. The results of this work may be valuable for conservators of cultural heritage institutions to determine optimal environmental conditions to limit the time-dependent degradation of historical paper artefacts.

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*Speaker