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Topic of Master's Thesis for

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Development of a Pore-Network Model for liquid consolidant imbibition in porous paint layers on Cultural Heritage

Paint layers in their simplest form consist of pigments and a binding medium. Paints which have been prepared with an insufficient amount of binding medium, once dried, are highly porous. The resulting paint layers are or can become cohesively weak, due to the degradation of the binding medium as result of environmental exposure. One conservation strategy, when there is a risk of material loss, is a consolidation treatment. Imbibition and evaporation mechanisms of liquids in porous paint layers play an important role in the conservation of cultural heritage. This topic is particularly relevant in the context of paint layer consolidation. For consolidating porous and cohesively weak paint layers conservators apply polymer solutions (often aqueous) onto the surface of the paint layer with a brush or as an aerosol. The aim is a homogeneous consolidation of the cohesively weak paint layer. These consolidation treatments, however, are carried out without the possibility to assess the solution's imbibition depth and the polymers' distribution after solvent evaporation. Experimentally validated pore-network models could potentially provide a valuable tool for studying the influence that

- the liquid consolidant's properties (viscosity, surface tension, wetting),
- the porous substrate's properties (pore geometry) and
- the environmental conditions (temperature and relative humidity)

have on the liquid consolidant's imbibition and evaporation during paint layer consolidation. This knowledge is currently lacking but crucial for performing controlled and targeted consolidation treatments on culturally valuable works of art.

The planned Master's Thesis will be affiliated to a research project currently planned at the Cologne Institute of Conservation Sciences (CICS) from the Cologne University of Applied Sciences and co-supervised by Prof. Dr. Ester Ferreira and doctoral candidate Charlotte Stahmann.

The task of this Master's Thesis is to assist in the research towards improved consolidation treatments using numerical modeling to complement the experimental works by Charlotte Stahmann at CICS. As the aim of the consolidation is homogeneous treatment of the paint layers and the imbibition process is, fundamentally, governed by the pore-scale geometry, the method of choice for this investigation are

pore-network models. Thus, the first task is to set up a simulation using the pore-network model [2, 3] implemented in DuMu^x (Dune for Multi-Phase, Component, Scale, Physics, ... flow and transport in porous media) to simulate the imbibition process by applying proper fluid properties, wettability state, boundary and initial conditions. Then, to extract the actual pore networks from the CT scans provided by the collaborators at CICS, using appropriate software, e.g. PoreSpy [1]. This will provide simplified, but realistic geometries to conduct the numerical investigations on.

The main tasks will be:

- Set up a pore network simulation using a simple network and applying proper fluid and porous medium properties.
- Extract one or more pore-networks from provided CT scans
- Perform pore-network model simulations of liquid consolidant imbibition into the pore network
- Perform a sensitivity analysis investigating the range of available consolidant properties, e.g. viscosity, surface tension and wetting behavior
- Compare results of pore-network model simulations to experimental observations by Charlotte Stahmann at CICS

The Master's Thesis shall be summarized in a report and presented in an oral presentation.

Examiner(s): Prof. Dr.-Ing Rainer Helmig
Supervisor(s): Maziar Veyskarami, Dr.-Ing Johannes Hommel
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[2] K. Weishaupt, A. Terzis, I. Zarikos, G. Yang, B. Flemisch, D. A. M. de Winter, and R. Helmig. A hybrid-dimensional coupled pore-network/free-flow model including pore-scale slip and its application to a micromodel experiment. *Transport in Porous Media*, 135(1):243–270, Oct 2020.

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