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1. Introduction

Indoor humidity regulation is essential for occupant comfort, energy efficiency, and indoor air quality. Hygroscopic materials such as clay passively buffer moisture fluctuations, reducing dependence on dehumidification systems. Additive manufacturing has facilitated the development of 3D-printed clay components with optimized exposed surface, improving moisture buffering capacity [1]. Although not a conventional construction material, clay is getting attention due to its low environmental impact, excellent moisture buffering capacity (high MBV 1.5-4 g/(m^2 %RH)) [1], and compatibility with Liquid Deposition Modeling (LDM) 3D printing [1]. However, accurately modelling of moisture transport in such complex geometries remains a challenge, with only one prior study addressing this issue [2]. Hygrothermal simulations play a crucial role in predicting the performance of moisture-buffering materials under real operating conditions. WUFI software has been widely validated and applied in passive indoor humidity regulation studies [3-5]. However WUFI is designed for flat building components, posing a challenge for modelling the hygrothermal behaviour of 3D-printed components with complex geometries. In this study, two modelling simplifications are applied to reproduce the moisture buffering behaviour of a 3D printed clay component. The first approach uses an equivalent flat material with the same exposed surface and volume as the 3D-printed component [2]. The second approach adopts an equivalent full-volume material that provides the same moisture buffering performance as the 3D-printed component. The effectiveness of these modelling strategies is assessed by comparing the results from numerical simulations to experimental data measured in the Moisture Buffering Value (MBV) test.

2. Methods

The study investigates a 5cm thick 3D-printed clay component with a complex geometry, designed to enhance moisture exchange with the surrounding air. Further details can be found in a previous study [1]. The methodology followed in the study is summarised in Figure 1.

The hygroscopic characterization of the material was done by measuring the water vapor resistance factor, water absorption coefficient, sorption isotherm, and porosity of the material, using flat samples. These data, together with thermal properties estimated based on the literature, provided the necessary input for the simulations. The MBV was measured using the Nordtest protocol, and the mass of the sample was tracked with a sampling interval of 1 minute. The MBV was measured for both a flat and a 3D printed clay component, both 5cm thick.

Hygrothermal simulations were developed using WUFI Pro. First, numerical simulations of the MBV behaviour were developed for a flat component, using the hygrothermal properties mentioned above, and a good fit was observed. The 3D-printed geometry was then simulated using the two approaches (I, II) described in the introduction. In approach (I) the material properties were those of the flat material. In approach (II) the water vapour permeability was adjusted to find a good fit with the measured MBV curve, aiming to define an "equivalent full volume material".

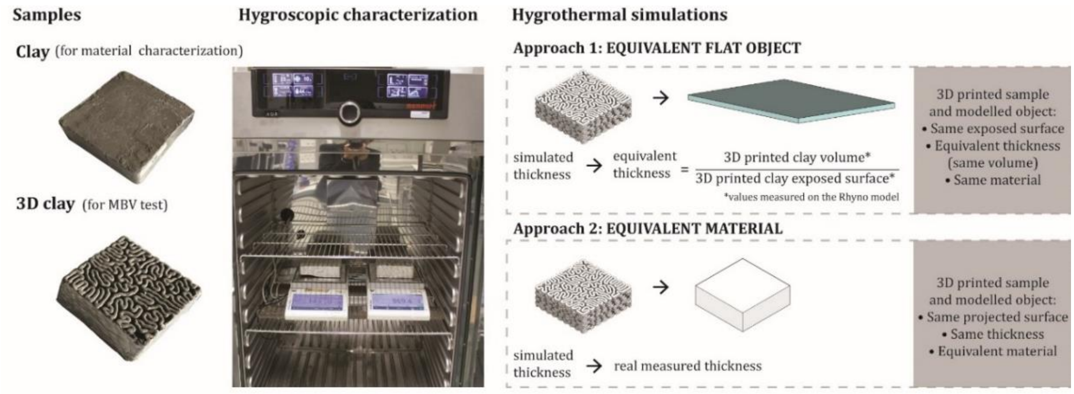

Figure 1. Methodology adopted.

3. Results

The MBV results are reported in Figure 2. They indicate that the 3D-printed clay component exhibits superior moisture buffering capacity compared to a plane sample having the same thickness, with an increase of 18%.

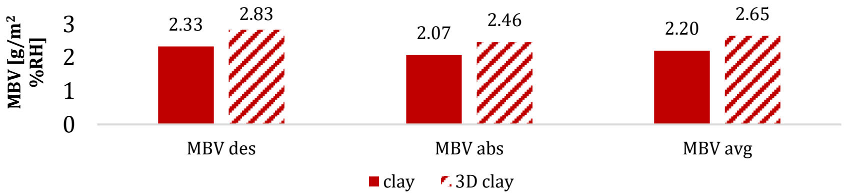

Figure 2. MBV measured through the Nordtest protocol using the flat and 3D printed clay samples.

Figure 3 shows the MBV data experimentally measured versus those simulated using approaches (I) and (II). Approach (I) results in a faster mass variation compared to measured data, both suring absorption and desorption. This is likely due to the assumption of a very thin material layer (1.4 mm), leading to rapid saturation of the material. Approach (II), shows a better agreement with the measured MBV data. Both simulation approaches give a good result in therms of MBV value, calculated considering the picks and falls in the mass variation curve, with approach (I) and (II) differing from the measured MBV of about 4% and 3%, respectively. It is worth noting that approach (I) results in an artificially accelerated moisture response due to the reduced material thickness. While this method accurately estimates the overall MBV, it may not reliably capture short-term indoor humidity fluctuations, such as peaks caused by activities like showering. In contrast, the approach (II) preserves the real thickness and thus provides a more realistic representation of dynamic moisture buffering behaviour for the component under study.

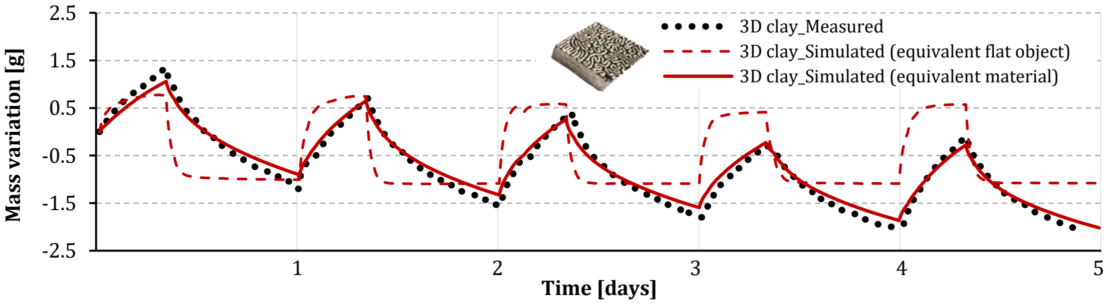

Figure 3. Validation of simulation models: comparison of measured and simulated curves of mass variation of samples.

4. Conclusion

This study presents preliminary results on the suitability of two different approaches for the numerical modelling of the moisture buffering behaviour of 3D-printed components with complex geometries. The findings indicate that the equivalent material approach offers a more accurate representation of the moisture buffering curve compared to the other approach (I), for the 3D-printed component under study. Both correctly estimate the MBV of the 3D-printed component. Given the scarcity of studies on the numerical modelling of MBV for 3D-printed components, this work aims to address this gap in the literature. Future research could explore their implementation in whole building hygrothermal simulations. Approach (I) could be adapted based on simplified non-visualised geometries, preserving the correct exposed surface interaction, as demonstrated in previous studies [2]. Approach (II) appears particularly suitable for building-scale applications by assigning validated equivalent material properties to indoor surfaces, maintaining the actual component thickness.

5. Acknowledgements

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