A Novel Integrative Design Framework Combining 4D Sketching, Geometry Reconstruction, Micromechanics Material Modelling, and Structural Analysis

S. Rasoulzadeh [a,1], V. Senk [b,1], M. Königsberger [b], J. Reisinger [a], I. Kovacic [a], J. Füssl [b], M. Wimmer [c]

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Abstract

State-of-the-art workflows within Architecture, Engineering, and Construction (AEC) are still caught in sequential planning processes. Digital design tools in this domain often lack proper communication between different stages of design and relevant domain knowledge. Furthermore, decisions made in the early stages of design, where sketching is used to initiate, develop, and communicate ideas, heavily impact later stages, resulting in the need for rapid feedback to the architectural designer so they can proceed with adequate knowledge about design implications. Accordingly, this paper presents research on a novel integrative design framework based on a recently developed 4D sketching interface, targeted for architectural design as a form-finding tool coupled with three modules: (1) a *Geometric Modelling* module, which utilises Points2Surf as a machine learning model for automatic surface mesh reconstruction from the point clouds produced by sketches, (2)a *Material Modelling* module, which predicts the mechanical properties of biocomposites based on multiscale micromechanics homogenisation techniques, and (3) a *Structural Analysis* module, which assesses the mechanical performance of the meshed structure on the basis of the predicted material properties using finite element simulations. The proposed framework is a step towards using material-informed design already in the early stages of design.

1. Introduction

Architecture, Engineering, and Construction (AEC) shapes our built environment, having a substantial environmental, cultural, and economic influence on society. However, among the least digitized industries, it is still caught in silo-thinking and sequential planning processes, as experts from different disciplines must work together and communicate throughout different stages of the design. Conventional AEC workflows typically involve a sequence of processes that are performed consecutively, with each domain expert performing their particular tasks (such as design, analysis and calculation) based on information and planning documentation from previous stages. While this approach helps reducing the complexity of the problem, it often leads to sub-optimal designs, as some important aspects may not be considered, and it may not be possible to make changes effectively in later stages [19]. In particular such sequential design process is error prone due to information losses between the steps and causes increasing planning costs and time due to long feedback loops. Further, it prevents creating joint knowledge and design optimisation in the earliest design stages, which are crucial for the latter building performance throughout the lifecycle. Unfortunately, the current professional fee structures still do not enhance integrated collaboration nor do these enhance additional efforts needed for the design optimisation in the early design stages. Thus, due to sequential planning practice, the flow of information exchange within current workflows between the domain experts with various domain knowledge is challenging, impeding optimised progression. A new approach to solve this problem is to closely connect Architecture, Computer Science, Engineering, Material Science and Mathematics to develop innovative computational design tools [62], combining implicit (e.g., aesthetical, cultural, or emotional) and explicit (e.g., functional, environmental, economic) knowledge. An important foundation for such tools would be the establishment of an integrative design framework that provides rapid feedback already in the early stages of design.

informed design strategies are thus increasingly popular [10], [49]. As an additional challenge, modern environmentally friendly construction materials such as biocomposites, a polymer matrix reinforced by natural fibres, come in large varieties, given the different fibres and polymers that are usable in different qualities and quantities, and given the different fibre orientations and different fibre lengths, which all lead to substantially different mechanical material properties [12]. These promising materials not only come in a very large variety but also show a more complex mechanical behaviour than conventional building materials. For this reason, it will become even more important to implement fundamental material understanding in the early planning phases. Therefore, multiscale material modelling approaches [35], [34], [27] are essential to characterize the performance of such materials.