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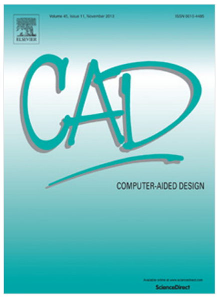

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A multi-physics approach for modeling hygroscopic behavior in wood low-tech architectural adaptive systems

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Abstract
Wood is a natural engineering material that has traditionally been exploited in design for a wide variety of applications. The recent demand for sustainable material and construction processes in the construction industry has triggered a renewed interest and research in the inherent properties of wood and their derived applications, and specifically for developing low-tech architectural adaptive systems. This paper focuses on the physical and computational modeling of the morphing behavior of wood through hygroscopic expansion or contraction to a high degree of precision. The amount of stress related to the hygroscopic shrinking or swelling ranges from almost zero to high values, and its prediction is fundamental to alleviate any fatigue challenges. The capability of designing wood composite whose stress state remains limited under changes of the environmental humidity is beneficial for any engineering application subjected to a repeated reversal of loading such as adaptive systems. In this paper, a mechanical model, together with its numerical implementation is presented; the model is benchmarked against and some prototypical experiments, performed by using real material parameters. The control parameter in the model is the relative moisture change in wood, that determines the orthotropic swelling/de-swelling phenomenon, and is coupled with the elastic behavior of wood. This model is integrated into a programmable matter design approach that combines physical and computational exploration. The approach is illustrated for a hygro-morphic building façade panel. The approaches and algorithms presented in this paper have further applications for computer-aided design of smart materials and systems with interchanging functionalities.

1. Introduction

The adoption of hygroscopic materials, and particularly wood, is compelling as a basis for low-tech smart materials and systems with interchanging functionalities in the construction industry. Certification processes that demand the use of sustainable construction materials and practices, drive the new demand for green materials that have a small carbon footprint in terms of manufacturing and operation. Traditional green materials such as wood are being re-examined for their inherent properties (e.g. hygroscopy) that have been unexploited in design in the past. Wood attracts or holds molecules from its surrounding environment and thus swells in volume as the water molecules then suspend between the cellulose fibers [1]; this property is called hygroscopy. This swelling (or shrinking) causes a volume expansion (or contraction) that may induce, or not, mechanical stresses in wood [2], [3], according to its properties at a fine scale (composition and fiber orientation), or at a coarse level (layering) in plywood. The realization of stress-free swelling and shrinking is key for the success of hygro-morphing building