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Modeling of wood-like cellular materials with a geometrical data extraction algorithm

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A R T I C L E I N F O

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A B S T R A C T

An algorithm on geometrical data extraction, material reconstruction and numerical analysis is presented in order to reconstruct the actual wood-like cellular materials and investigate their linear elastic material behavior in the transverse plane under different loading conditions. The algorithm implemented by Mathematica technical computing software is used to read the pixel data of cellular material images with a wide range of material scales, e.g. from micro- to millimeter scale. As a result of this process, geometrical properties including cell wall thicknesses, cell connectivities, vertex and center coordinates are determined. Identified geometrical properties are transferred to Abaqus/CAE computer aided engineering software by using a Python script and also converted into stereolithography STL model format enabling prototype generation and visualization. As an application example, the reconstructed model by means of the algorithm was used to investigate the in-plane effective stiffness properties of Norway spruce earlywood specimens in the frameworks of homogenization and finite element analysis.

1. Introduction

The increasing computation power, and emerging image processing and reconstruction technologies have given rise to the investigation and visualization of the geometrical and mechanical properties of materials. Especially in the field of cellular material science, these technologies can provide accurate geometrical data for mechanical analysis and insight into modeling and design procedures (Farrugia and Perre, 2000; Magne, 2007). As a result, modeling errors due to geometrical input can be reduced and accuracy of the simulation experiments can be enhanced.

Yet studies on cellular materials do not widely use the image processing technologies to determine the material geometry and use it as an input for simulation experiments. The conventional approach follows the representation of the whole material with regular repetitive unit elements, i.e. hexagonal, rectangular, etc., and investigations into the mechanical behavior of these elements (Gibson and Ashby, 1997; Qing and Mishnaevsky, 2011; Freund et al., 2014). Although results out of this approach can be regarded satisfactory, modeling errors due to fictitious geometrical input are inevitable. In the literature, there are successfully conducted studies that use the data extraction and image reconstruction algorithms to determine geometrical input for the material models and simulations. Such studies benefit the accuracy of electron and transmission electron microscopy, nuclear magnetic resonance NMR imaging, X-ray projection, synchrotron radiation X-ray tomography and micro computed

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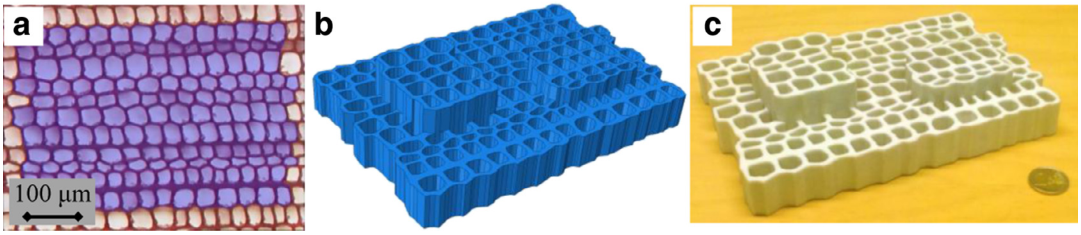

Fig. 1. (a) Norway spruce earlywood cross-section and region of interest with transparent coloring, (b) extruded near-exact model of the region in STL format, (c) corresponding three dimensional print.

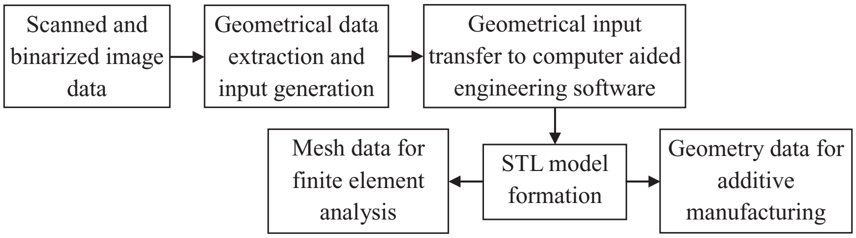

Fig. 2. Algorithm sequence.

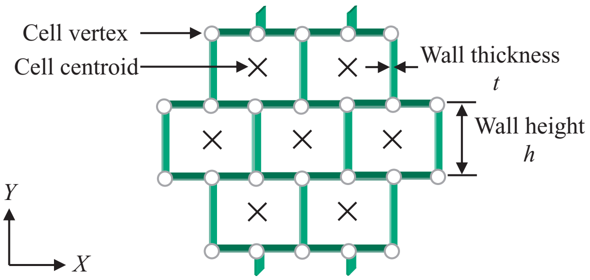

Fig. 3. Schematic representation of geometrical features for a cellular material in the transverse plane.

tomography, especially in aerospace, biological, agricultural, medical and dental applications (Kahle and Woodhouse, 1994; Cattaneo et al., 2001; Verdonschot et al., 2001; Badel and Perre, 2003; Zdunek et al., 2004; Nguyen et al., 2012; Karakoç and Freund, 2013; Rafsanjani et al., 2012). Despite the high accuracy of these techniques, expensive equipment and maintenance, sophisticated algorithms and lack of qualified labor obstruct their extensive usage in many engineering applications.

As its novelty, the present algorithm provides a low equipment and labor cost solution to visualize and investigate the geometrical and mechanical characteristics of cellular media. The algorithm is capable of extracting geometrical data and reconstructing cellular materials within a wide range of material scales, e.g. micro- to millimeter scales. In addition, the algorithm also brings appropriate geometrical input parameters for multiscale characterization of arbitrary cell collections in two dimensional space. Hence, it is possible to estimate the in-plane effective mechanical properties of cellular materials through the material description at the cell scale in the frameworks of homogenization and finite element analysis.

In the present study, first, the sequence of the algorithm is introduced and the principles are explained. Thereafter, an application example is provided, for which two-dimensional micrographs of Norway spruce specimens were captured with optical microscopy as depicted in Fig. 1. In this example, earlywood cross-sections of Norway spruce specimens in the transverse plane was investigated, for which image processing, stereolithographic STL modeling and finite element analysis were used. The accuracy of the proposed algorithm was tested in terms of the empirical and computed effective stiffnesses for Norway spruce earlywood available in the literature.

2. Materials and methods

2.1. Algorithm sequence

The introduced algorithm follows the sequence described in Fig. 2. The starting point is to scan the cellular material layer in the plane of interest and to binarize the image. The binarization data is then used to extract the geometrical information of the cellular structure. The geometrical information is used to form so called near-exact STL models in the present study, which are then used to generate mesh for finite element analysis and prototypes for additive manufacturing. These prototypes are helpful to visualize and understand the geometrical models and details.

2.2. Geometrical data extraction algorithm

The proposed geometrical data extraction and input generation algorithm is an automated set operation coded in Mathematica technical computing software. The algorithm extracts the near-exact features of the cellular material including the cell centroids and vertices, cell wall heights h and thicknesses t as illustrated in Fig. 3. Once these geometrical features are known, it is possible to reconstruct models from image to insight for visual inspections, material prototyping and numerical analyses.