Doctoral Dissertation
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Hierarchical component-wise models for enhanced stress analysis and health monitoring of composites structures

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The simulation of composite structures demands the introduction of novel computationally-efficient models that must overcome the limitations of traditional metallic-oriented FEM codes. The multiscale nature of composite materials represents a great challenge from the modeling perspective and has reduced the confidence of engineers in the simulation tools, leading to the introduction of higher safety margins in the industry. As a consequence, the use of innovative solutions that exploit the advantages of composite materials in terms of specific properties and design variables is always penalized and, therefore, less attractive.

Addressing this issue, this thesis focuses on the development of a robust formulation for the mechanical analysis of composite structures at different scales. The Carrera unified formulation (CUF) is employed to generate a new beam theory based on a hierarchical non-local expansion of the mechanical variables over the cross-section: the hierarchical Legendre expansion (HLE). The finite element method (FEM) is employed to solve the governing equations of static and dynamic problems. Two classes of locking-free straight and curved beam elements are implemented by means of the mixed interpolation of tensorial components (MITC) method. The modeling of composites is based on a component-wise (CW) approach, for which the different constituents of the structure are kinematically independent.

The applications of the proposed model are divided in two parts: the first addresses the efficient computation of 3D stress fields, covering topics such as micromechanics, mixed elements based on the Reissner mixed variational theorem (RMVT) and free-edge analysis; the second part addresses the structural health monitoring (SHM) of metallic and composite structures, focusing on the use of higher-order structural theories for the time-domain analysis of Lamb waves. All the proposed theories and applications presented in this thesis are verified via analytical and numerical references.