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OpenSG: A FEniCSx-Based Implementation of the Mechanics of Structure Gene with Emphasis on Aperiodic Beams

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Software

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Summary

OpenSG is an open-source platform for multiscale structural mechanics built with a FEniCSx (Baratta et al., 2023) backend. It implements the Mechanics of Structure Genome (MSG) theory (Wenbin Yu, 2019), a unified and rigorous framework for modeling advanced structures with general anisotropy and heterogeneity, including beams, plates, shells, and continuum structures.

OpenSG is a micromechanics code, which means it enables users to effeciently incorporate small-scale details into the global structural scale. This involves two primary steps, homogenization and dehomogenization. Homogenization is the process of obtaining homogenized structural properties whereas, dehomogenization is recovering the local stress and displacement fields. These operations are performed over a user-defined domain called the Structure Gene (SG). An SG can be 1-dimensional (line elements), 2-dimensional (quadrilaterals or triangular elements), or 3-dimensional (hexahedron or tetrahedron elements). Using SGs, OpenSG produces structural properties in terms of Cauchy continuum model, plate/shell model, or beam model. Conventional finite element analysis tools can utilize these properties to output global structural responses. OpenSG can use these responses to compute small-scale stresses and deformations throughout the SG. In this way, OpenSG provides an accurate, fast, and versatile platform for analyzing structural profiles with key small-scale details like aircraft, wind turbine blades, and additively manufactured parts.

Statement of need

The MSG theory was first implemented in SwiftComp (Wenbin Yu, 2016), a commercial code. It offers unification of the following codes: VAMUCH for unit cells of materials (Wenbin Yu et al., 2003), VAPAS (Wenbin Yu, 2005) for plates and shells, and VABS (W. Yu et al., 2002) for beams. In addition to replicating the core of SwiftComp's capabilities (Bagla et al., 2023), OpenSG extends the MSG theory to allow for aperiodic beam SGs made of either shell (Bagla et al., 2024, 2025a) or solid (Bagla et al., 2024) elements. This is particularly useful for modeling nonprismatic structures and for accounting for 3D phenomenon, such as panel buckling. Some examples of nonprismatic structures are airplane wings, propellers, offshore jacketed structures, wind blades, tapered tubes and rods, non prismatic bridges.

Compared to other beam property computation tools such as BECAS (Blasques, 2012) and PreComp (Bir, 2005), OpenSG is unique in that it goes beyond beam-only models, also supporting shell and solid formulations within a single MSG-based framework.

Recent research has already demonstrated the utility of OpenSG in advancing structural analysis of composite structures, including 3D shell-to-beam modeling (Bagla et al., 2024) and wind turbine blade modeling (Bagla et al., 2025b). These applications highlight the potential of OpenSG to enable accurate, scalable, and open-source solutions for structural modeling challenges across wind energy and beyond.

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OpenSG has been developed within the Holistic, Multi-Fidelity Wind Farm Design Optimization and Model Coordination project under the U.S. Department of Energy Wind Energy Technologies Office. It is currently being evaluated for its suitability to transform wind turbine blade design, mainly due to its ability to incorporate high-fidelity structural details into efficient beam models.

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References

Bagla, A., Camarena, E., & Yu, W. (2024). Three-dimensional structural analysis of shell structures using MSG based beam model. *Proceedings of the American Society for Composites-Thirty-Ninth Technical Conference*.

Bagla, A., Camarena, E., & Yu, W. (2025a). Theory of arbitrary shaped thin-walled composite beams. *Proceedings of the American Society for Composites-Fortieth Technical Conference*.

Bagla, A., Camarena, E., & Yu, W. (2025b). Timoshenko beam modeling of realistic wind turbine blades using mechanics of structure genome. *Proceedings of the ASME 2025 International Mechanical Engineering Congress and Exposition (IMECE2025)*.

Bagla, A., Yu, W., & Camarena, E. (2023). OpenSG: An open-source multiscale constitutive modeling code for composite structures and materials. *Proceedings of the American Society for Composites-Thirty-Eighth Technical Conference*.

Baratta, I. A., Dean, J. P., Dokken, J. S., Habera, M., Hale, J. S., Richardson, C. N., Rognes, M. E., Scroggs, M. W., Sime, N., & Wells, G. N. (2023). *DOLFINx: The next generation FEniCS problem solving environment*. preprint. https://doi.org/10.5281/zenodo.10447666

Bir, G. S. (2005). *User's guide to PreComp (pre-processor for computing composite blade properties)*. National Renewable Energy Laboratory (NREL), Golden, CO. https://doi.org/10.2172/876556

Blasques, J. P. A. A. (2012). *User's manual for BECAS: A cross section analysis tool for anisotropic and inhomogeneous beam sections of arbitrary geometry* (Technical Report Risoe-R-1785(EN)). Risø DTU – National Laboratory for Sustainable Energy, Denmark. Forskningscenter Risoe.

Yu, Wenbin. (2005). Mathematical construction of a reissner–mindlin plate theory for composite laminates. *International Journal of Solids and Structures*, *42*(26), 6680–6699.

Yu, Wenbin. (2016). *SwiftComp user manual*.

Yu, Wenbin. (2019). Simplified Formulation of Mechanics of Structure Genome. *AIAA Journal*, *57*(10), 4201–4209. https://doi.org/10.2514/1.J057500

Yu, Wenbin, Hodges, D. H., & Volovoi, V. V. (2003). Asymptotically accurate 3-d recovery from reissner-like composite plate finite elements. *Computers & Structures*, *81*(7), 439–454.

Yu, W., Hodges, D. H., Volovoi, V., & Cesnik, C. E. S. (2002). On timoshenko-like modeling of initially curved and twisted composite beams. *International Journal of Solids and Structures*, *39*(19), 5101–5121. https://doi.org/10.1016/S0020-7683(02)00399-2