ROBOTIC ADDITIVE MANUFACTURING OF NATURE-INSPIRED, TOPOLOGY OPTIMIZED, AND MULTIFUNCTIONAL SMART MATERIALS-BASED DESIGNS

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- Prof. Dr. **Dante Jorge Dorantes-Gonzalez** (Principal Researcher)

  Biography. Prof. Dorantes holds master's and doctoral degrees in Manufacturing Automation from Saint-Petersburg Technical University. He has held key academic positions, including Head of the Department of Mechanical and Mechatronics Engineering at the Monterrey Institute of Technology in Mexico. He later worked at Tianjin University in China and now serves as full-time faculty member in the Department of Mechanical Engineering at MEF University in Istanbul, Türkiye. His research spans laser ultrasonics, laser-based measurement, mechatronics, robotics, and neuroscience-based learning. He has authored six textbooks, four book chapters, over 80 peer-reviewed papers, and holds eleven patents. He is an active member of international scientific committees and editorial boards.

- **MEF University** is a non-profit university in Istanbul, Türkiye, committed to graduating globally competitive, forward-thinking students. Known for its high academic standards and innovative approach, MEF is the world's first university to fully adopt the **Flipped Classroom** model across all programs. MEF offers 15 undergraduate programs in Engineering, Architecture, Law, Education, Business, Economics, and Social Sciences. All engineering programs are **ABET-accredited**, and instruction is in English.

- **THE TEAM**:
  - Mostafa Saleh (MEF University's Mechanical Engineering Department); Murat Saribay (Bilgi University's Mechanical Engineering Department); Metin Kayıtmazbatır (Istanbul Technical University's Mechanical Engineering Department); Sema Alaçam (Istanbul Technical University's Department of Architecture).
  - Altinay Robotics SME (Istanbul, Türkiye)
  - Filippos Tzanetos and Lukas Hedwig (FH Aachen, Mech. Eng. and Mechatronics Faculty, Inst. of Applied Automation and Mechatronics).

PROJECT DESCRIPTION

This multidisciplinary research project pioneers a novel design and manufacturing framework that merges nature-inspired principles, multifunctional smart materials, and topology optimization with multiaxis robotic additive manufacturing technologies.

The project establishes a comprehensive methodology that draws from nature-inspired structures to create lightweight, structurally efficient, smart **environmentally-friendly** functional materials with sensors, and integrated electronics. It integrates topology and field optimization techniques to reduce material use while maintaining mechanical performance in applications ranging from aerospace parts to smart consumer and artistic products **produced** by a multi-axis robotic additive manufacturing system.

The expertise currently aligns with Technology Readiness Levels (TRL) 2–4 levels. The project goal is for the 3-year project to produce a prototype that reaches TRL 6–7 validation to enable commercialization.

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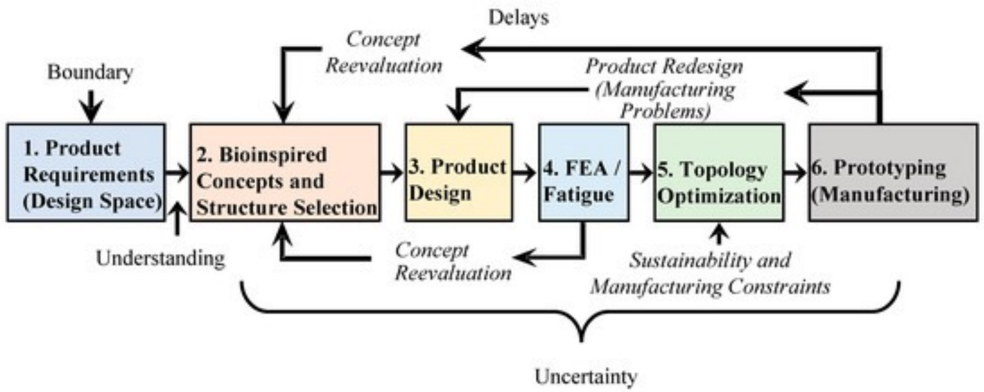
- GOALS:
  1. Establish a nature-inspired product design methodology enhanced with multifunctional smart materials and integrated electronics.
  2. Bridge the gap between industrial design aesthetics and engineering testing techniques for the design of complex geometries.
  3. Optimize the structural performance through topology and field optimization.
  4. Conduct research on additive manufactruing processes to produce hybrid multifunctional, smart, and environmentally-friendly materials.
  5. Implement the designs in a multi-axis large-scale robotic additive manufacturing system up to TRL 6–7 validation and commercialization.
- IMPACT:
  - **SCIENTIFIC**. Besides the academic value, the project will generate multiple peer-reviewed articles, conference papers, a book, contributing new knowledge on the integration of nature-inspired design with robotic additive manufacturing.
  - **INNOVATION**. Development of the know-how for robotic additive manufacturing leading to several patents, influencing industries such as aerospace, biomedical, automotive, architectural, and the fine arts. It also aims commercialization through the creation of a technological startup.
  - **UNIVERSITY-INDUSTRY COLLABORATION**. The partnership with Altınay Robotics, and other international companies ensures that research findings translate into scalable, industry-ready robotic additive manufacturing solutions
- POTENTIAL RESULTS:
  - A novel nature-inspired product design **methodology**; the **know-how** of robotic additive manufacturing of nature-inspired, topology-optimized and multifunctional material-based designs; several **SCI publications** and conference articles; **patents**; university-industry collaboration; **startups**.

EXPERTISE

Category	Stimulus	Response	IF Condition	THEN Condition
Mechanical Properties	Load	Stiffness	**IF** the structure must resist deformation under applied load	**THEN** use columnar lattices (tree trunks, coral skeletons) for high rigidity and minimal deflection or shape memory alloys (SMAs) for adaptive stiffness
		Strength	**IF** structure must withstand high loads before breaking	**THEN** use Voronoi lattices (trabecular bone, radiolarians) for efficient stress distribution and fracture resistance or carbon-fiber reinforcements for high tensile and compressive strength.
		Toughness	**IF** material must absorb impact without fracturing	**THEN** use multi-layered structures (nacre, tree bark) for energy dissipation and crack resistance or use shear-thickening fluids (STFs) for adaptive impact absorption and shock resistance.
	Porous Impact Resistance	Gradient-Based Shock Absorption	**IF** material must absorb impact energy efficiently through porosity	**THEN** use biologic porous structures (trabecular bone, pomelo peel) for energy dissipation via density gradients or Nature-inspired foams for controlled impact resistance
	Repetitive Load (Fatigue Stress)	Fatigue Resistance	**IF** the structure experiences repeated loading cycles	**THEN** use tree-like branching structures (Acropora hyacinthus, vascular networks) or self-healing polymers for micro-crack repair
	Torsion Shear Stress	Torsional Rigidity	**IF** the structure must withstand torsional (twisting) forces	**THEN** use spiral structures (DNA helix, seashells) or magneto-rheological elastomers (MREs) for tunable stiffness
	Dynamic Impact Load	Energy Dissipation	**IF** the material must withstand high-energy impact	**THEN** use Voronoi lattices (radiolarians, trabecular bone) or piezoelectric transducers for real-time impact sensing
	Resonant Frequency & Damping Response	Damping Capacity	**IF** product must dampen or control vibrations	**THEN** use wave-like patterns (fish fins, sand dunes) or electro-rheological fluids (ERFs) for active damping



Ryan-Johnson, W. P., Wolfe, L. C., Byron, C. R., Nagel, J. K., & Zhang, H. (2021). A Systems Approach of Topology Optimization for Bioinspired Material Structures Design Using Additive Manufacturing. *Sustainability*, *13*(14), 8013. https://doi.org/10.3390/su13148013

Table 11. Analysis Results for nTop.

Material Type	Displacement (mm)	Strain	Stress (MPa)	Performance Parameter (Stress/Strain)
Al 6061	0.24	0.00045	32.18	7.15×10^{10} Pa
ABS	7.34	0.0134	30.90	2.31×10^{9} Pa

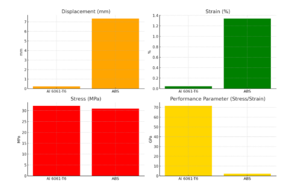
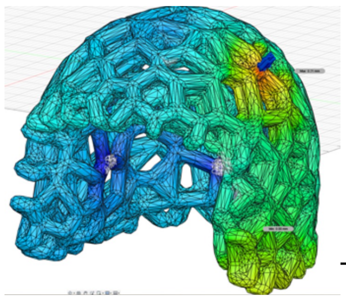
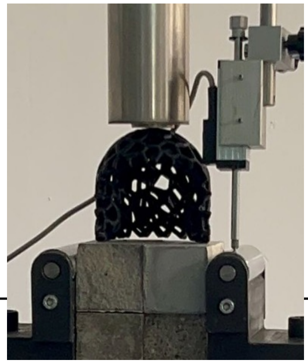
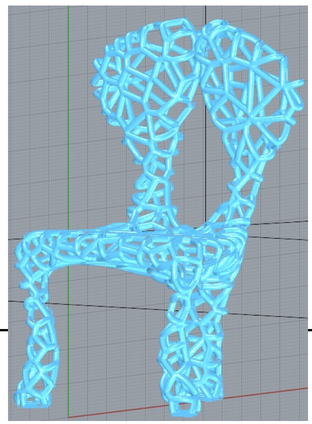
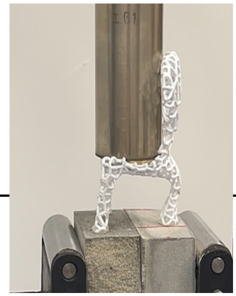


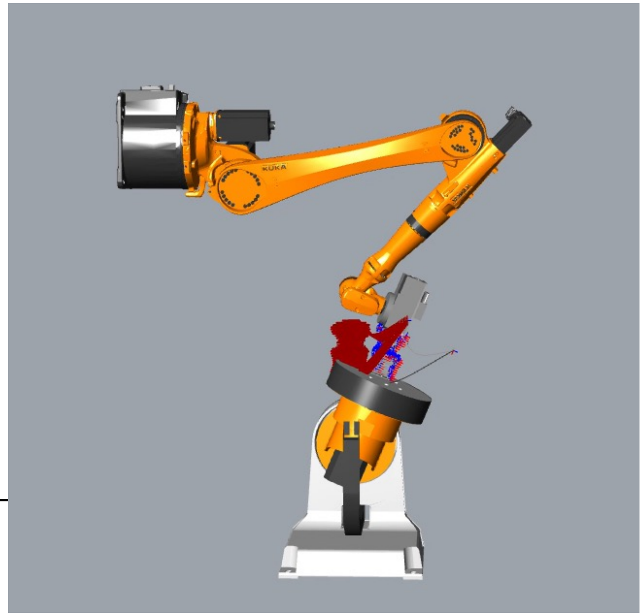
Figure 289. Graphics of Analysis Results in nTop.











SPECIFIC DETAILS OF NEEDS

1. R&D of Additive manufactruing processes for hybrid multifunctional, smart, and environmentally-friendly materials and structures with integrated electronics.
2. Life-Cycle Design and Assessment.

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