POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 40th cycle

THEMATIC Research Field: BIO-INSPIRED WASTE-DERIVED META-ARCHITECTURES FOR DIGITAL SUSTAINABLE BUILDINGS

Monthly net income of PhDscholarship (max 36 months)
€ 1500.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Buildings account for over 30% of global energy use and 19% of greenhouse gas emissions. They significantly impact the environment, consuming vast natural resources and contributing to global warming. Due to their environmental impact, there is an increasing focus on evaluating and reducing these effects. This has led to the concept of Net-Zero Energy Buildings (NZEBs), which generate as much energy as they consume annually. Advancements in digital technologies and fabrication are crucial for reducing embodied CO2 and improving building sustainability. Innovative design solutions, such as topological optimization To achieve NZEBs, there is a need to bridge the gap between digital technologies and sustainable materials. Current computational models struggle to accurately represent complex natural materials. A validated multi-scale digital model could demonstrate the functionality of bio-waste derived meta-structures, reducing the need for costly experimental campaigns. The "digital based bio-waste derived meta-PANels Towards A REvolutionary building Identity" (**PANTAREI**) project aims to design and assess novel bio-waste-derived meta-structures to reduce embodied CO2 in buildings. PANTAREI will develop adaptive computational tools for bio-inspired material design based on physics of failure and non-equilibrium thermodynamics. This project promotes digital design and fabrication, enabling the generation of climate-neutral, sustainable, and inspiring

	buildings. PANTAREI **aims** to achieve NZEBs by synergizing adaptive multi-scale models, bio- derived materials, and a human-centered framework. This approach allows for adaptive digital design and scaling of bio-waste derived meta-structures to reduce embodied CO2 in construction. The methodology will be validated through a case study designing thermal-efficient panels inspired by bone architecture, using 3D-printed recycled transparent wood, thermoplastic polyurethane, wheat stem fibers, and eggshell powder. These panels offer benefits like UV-blocking, thermal insulation, and aesthetic appeal.
Methods and techniques that will be developed and used to carry out the research	This research requires a multi-faceted range of methods and techniques to investigate a novel triad of digital design, digital fabrication and bio-derived materials and to translate this understanding to the design of sustainable meta-structures, including: 1. Adaptive multi-scale meta-material modeling, to generate a novel database of bio-derived material properties and mechanical/thermal responses and to predict their behaviour to external stimuli; 2. Bio-inspired design, to seek inspiration from natural efficient multi-scale architectural organization; 3. 3D printing of novel bio-waste derived materials complex structure realization; 4. Multi-scale mechanical testing to study material mechanical properties, including its strength, toughness, and elasticity; 5. Computational modeling, to simulate damage evolution, weakening and toughening phenomena at the multi-scale, including extended finite element (XFEM) strategies to model fracture progression; 6. Imaging techniques: micro-computed tomography, synchrotron analyses, scanning electron microscopy are especially useful for identifying microstructural features that may contribute to a material resilience; 7. Image analysis, adopting effective artificial intelligence-based tools for the post-processing of large size

	datasets, such as high-resolution imaging.
Educational objectives	This cutting-edge research perspective on tailored green solutions for net-zero energy buildings is a unique opportunity for PhD students to: 1. Elucidate the complexity of the multi-scale structure and characteristics of bio-waste derived materials, as well as the fundamental principles governing their response to damage towards sustainable engineered solutions. 2. Employ a diverse array of methodologies and approaches, encompassing advanced imaging techniques, mechanical testing, and computational modeling, to investigate and analyze these meta-materials. 3. Cultivate critical thinking and problem-solving abilities while nurturing innovation and creativity by providing guidance to doctoral students in the creation of novel sustainable structures that exhibit improved mechanical and thermal properties. Establish interdisciplinary collaboration among students and faculty from various disciplines, including biomechanics, physics, computer science, mechanical engineering, and material engineering, to foster cross-pollination of ideas and expertise.
Job opportunities	Our last survey on MeccPhD Doctorates highlighteda 100% employment rate within the first year and a 35% higher salary, compared to Master of Science holders in the same field. This project has received funding from The European Innovation Council (EIC) within the framework of EIC Pathfinder Challenge: AEC digitalisation for a new triad of design, fabrication, and materials, Grant agreement ID: 101161602. List of Universities, Companies, Agencies and/or Nationalor International Institutions that are cooperating in the research include: 1. TU, Delft - bio-inspired meta-materials; 2. University of Luxembourg - artificial

	intelligence strategies for human-centered design; 3. University of Derby - adaptive multi-scale modelling; 4. 10XL - company working in the field of advanced bio-printing; 5. Fantoni - company working on sustainable strategies for panels.
Composition of the research group	1 Full Professors 0 Associated Professors 1 Assistant Professors 7 PhD Students
Name of the research directors	Prof. Laura Maria Vergani

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	750.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
Financial aid is available for all PhD candidates (purchase of study books and materials, fundingfor participation in courses, summer schools, workshops and conferences) for a total amount of € 6.114,50. Our candidates are strongly encouraged to spend a research period abroad, joining high-level research groups in the specific PhD research topic, selected in agreement with the Supervisor.An increase in the scholarship will be applied for periods up to 6 months (approx. 750 euro/month- net amount).Teaching assistantship: availability of funding in recognition of supporting teaching activities by the PhD candidate. There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.