POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

Number of scholarship offered	7
Department	DIPARTIMENTO DI MECCANICA

Description of the Research Area

Research on advanced materials and smart structures is playing a crucial role in all the branches of mechanical and production engineering. The design and development of innovative materials is relevant to enhance specific functional properties customized on engineering applications. Both the innovative and existing materials require new processes to enhance material performance, to integrate new features and/or reduce the effect on the environment (i.e., eco-friendly production).

New (numerical and experimental) multiscale models have to be investigated in order to characterize the mechanical behaviour of materials under different service conditions and degradation patterns. Moving from the material to the component and then to the mechanical systems, smartness and metamaterials can further help reaching customized functional performance. Development of smart materials, smart components and integrated measurement and control systems can lead to significant benefits (e.g. structural health monitoring, vibration attenuation, energy harvesting, quality control).

Eventually, advanced modelling and experimental investigation of the interaction between the structure and the environment (e.g., bridge aeroelasticity, tall buildings and roof aerodynamics, cable dynamics) can aid designing a new generation of large structures where dynamic control is included at the design level.

There are 7 available scholarships in this area:
- 1 generic
- 3 thematic (to be specifically selected during application procedure)
- 3 interdoctoral (to be specifically selected during application procedure)

The generic scholarship refers to the following field:

- Advanced Modelling and Testing of Materials for Machine Design

3 thematic scholarships, on the following topics:
- Actively controlled system to test bridge decks in wind tunnel
- Metamaterials for cloaking and acoustic stealth
- Innovative materials and advanced processes

***One thematic interdoctoral scholarship, jointly supervised by the PhD Programme in Mechanical Engineering and by the PhD Programme in Mathematical Models and Materials in Engineering, is available on the following research topic*:**
Real-time optimal control and monitoring of mechanical structures by PDE constrained optimization and reduced order modeling

One thematic interdoctoral scholarship, jointly supervised by the PhD Programme in Mechanical Engineering and by the PhD Programme in Sructural Seismic and Geotechnical Engineering, is available on the following research topic:
Tailored piezoelectric materials and optimally designed metamaterials for enhanced mechanical energy harvesting

***One thematic interdoctoral scholarship, jointly supervised by the PhD Programme in Mechanical Engineering and by the PhD Programme in Industrial Chemistry and Chemical Engineering, is available on the following research* topic:**
Smart technologies for vertical and precision farming

Applicants should select thematic scholarships following the instructions provided in the call for application/application procedure.

The PhD scholarships available in this area are partially funded with the support of the Italian Ministry of Education, University and Research, through the project Department of Excellence LIS4.0 (Integrated Laboratory for Lightweight e Smart Structures).

Further information on the thesis topics available in this can be found at the following link: https://www.mecc.polimi.it/us/phd/admission/

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

THEMATIC Research Field: ACTIVELY CONTROLLED SYSTEM TO TEST BRIDGE DECKS IN WIND TUNNEL

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch,during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The design of long span bridges is based on their aerodynamic performances that are studied in wind tunnel and simulated through numerical simulations. Wind tunnel tests on deck sectional models are the basis to check the bridge aerodynamic stability and to measure the aerodynamic coefficients required by the numerical simulations. Tests are usually performed using passive test rigs with deck rigid models suspended on spring and motion controlled test rigs with deck rigid models connected to actuators. Aim of the present research is to investigate the possibility to exploit active control logic to simulate the aeroelastic behaviour of a bridge deck by a hardware-in-the-loop (HIL) strategy to emulate the structural response of a bridge exposed to turbulent wind. The objective is to have a test rig where the deck sectional model is connected to actuators that are able to move the model itself as it were suspended on the bridge main cables once it is exposed to the wind. For this purpose, a control logic has to be developed to allow the actuators to provide to the model the forces and the displacement the main cables would transmit in a real-life situation when the deck is exposed to aerodynamic loads.
Methods and techniques that will be developed and used to carry out the research	The PhD candidate will develop the control logic of a new wind tunnel setup recently implemented in the Politecnico

	di Milano wind tunnel composed by 6 electric actuators allowing for the position control of a deck sectional model in the high speed test section of the experimental facility. An initial dynamic characterization of the system and of all its components will be performed. This information will be used in a HIL control logic to experimentally simulate the aeroelastic response the deck model would have if it were suspended through hangers to the bridge main cables reproducing the correct parameters of stiffness and damping. To this aim, the instantaneous aerodynamic force measured on the model has to be introduced in a simulation of the system aerodynamic response running simultaneously to the experiment to provide to the actuators the value of the corresponding force and position to be applied to the model.
Educational objectives	The PhD candidate will be working in one of the most challenging research fields of wind engineering and design of long span bridges. The PhD candidate will become an expert in advanced modelling belonging to different fields of engineering. The candidate is supposed to provide original contributions to the development and verification of numerical and experimental tools for simulating bridge aeroelastic response. The relationships established with international experts in this field will enable the candidate to develop the capability to cooperate within an international high level research team.
Job opportunities	Future job opportunities are primarily in the wind engineering field, including engineering companies, engineering and project management companies, operators and infrastructure managers. In a more general way, the competence acquired will indisputably be of interest for R&D departments of companies dealing with issues related to road/railway infrastructure design. Besides this, job opportunities will be with national and international academic and non-academic institutions and organizations, engaged in innovation, research and technical development. Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared to

	Master of Science holders in the same field.
Composition of the research group	5 Full Professors 5 Associated Professors 0 Assistant Professors 2 PhD Students
Name of the research directors	Prof. Daniele Rocchi, Prof. Tommaso Argentini

Contacts
Phone: +39 02 2399 8458 Email: daniele.rocchi@polimi.it Email: phd-dmec@polimi.it

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of 5401,42 euro. Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). 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. 550 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.

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

OPEN SUBJECT Research Field: ADVANCED MODELLING AND TESTING OF MATERIALS FOR MACHINE DESIGN

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch,during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Working in the Machine and vehicle design group requires motivation in developing experimental and computational methods for the assessment of the structural integrity and advanced design of mechanical components and vehicles. The objectives of the research may range from the definition of new models of materials behaviour to the assessment of the structural integrity of large structures, from the experimental investigation on new materials (or materials processed with new manufacturing processes) to the design of components or vehicles with innovative features. In particular, the attention may be addressed to the detailed fatigue and fracture assessment of additively manufactured critical components, as well as to the design of structures under extreme loading conditions focusing on composite components subjected to impacts and blast loading.
Methods and techniques that will be developed and used to carry out the research	Depending on the specific research topic assigned, methods and techniques will comprise finite element modelling, boundary element modelling, fracture mechanics, multi-axial fatigue tests on specimens or on parts, non-destructive tests, high temperature tests, residual stress tests, tests on vehicle components, tests on gears, tests on power transmission.

Educational objectives	The Doctor in Mechanical Engineering will be able to define, start and carry out original research by working in a team or leading a research group. Both theoretical and experimental skills are mastered.
Job opportunities	Structures/organizations aimed at innovation and/or research and technical development, high-tech SMEs, government departments ruling on public needs. The following Companies, Universities and Institutions are cooperating in the research: Tenaris Dalmine S.p.A Leonardo S.p.A. ENI S.p.A Technical University of Clausthall, German MIT, Boston, USA Imperial College London University of California at Berkeley European Space Agency (ESA) Auburn University, National Center for Additive Manufacturing Excellence (NCAME) Avio-Aero, Rivalta (To) EAMIT (Pr) Thales Alenia Space Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared to Master of Science holders in the same field.
Composition of the research group	6 Full Professors 14 Associated Professors 6 Assistant Professors 25 PhD Students
Name of the research directors	P. Giglio,Beretta,Gobbi,Guagliano,Mastinu,Vergani

Contacts
First contact, to be redirected to one of the research directors: Prof. Chiara Colombo chiara.colombo@polimi.it. For questions about scholarship/support:phd-dmec@polimi.it.

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of euro 5401, 42.

Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). 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. 660 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.

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

THEMATIC Research Field: INNOVATIVE MATERIALS AND ADVANCED PROCESSES

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch,during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The demand arising from technological innovations driven by the uptake of new manufacturing processes and improved product performance, is strongly motivating the development of innovative structural and functional materials with advanced and new properties.Future materials need to be designed/optimized according to their specific processing route (e.g. materials for additive manufacturing), need to possess specific thermal and physical properties to fulfill special functions (e.g. phase change materials for thermal storage) could preferably show variation of their properties within the volume of a single components (e.g. multi-materials, gradient 3D lattices, metal-ceramic composites). Even more, they could act as smart materials adding a further dimension to materials science, being able to react to external stimuli by providing a change in their behaviour or properties. In addition, metalworking processes also require extensive innovation to allow the control of both traditional and new materials according to reliable, cost-effective and sustainable criteria.Several research projects are available within this frame. Details about the specific topics will be supplied on request.
Methods and techniques that will be developed and used to carry out the research	The Material research group has expertise on microstructural and mechanical characterization of advanced metallic alloys. The methods to be used will

	involve Thermodynamic modelling of alloy microstructure, tools for experimental analyses on phase and microstructure analyses (optical and electron microscopy, EBSD, XRD, DSC) and mechanical characterization among others by tensile testing, fracture toughness, fatigue testing, creep. For more details about infrastructures, see: https://www.mecc.polimi.it/us/research/departmental-laboratories/
Educational objectives	At the end of the PhD cycle the candidate will be able to define, design and carry out original research programs by working in a team or leading a research group in the field of smart materials. Opportunities will be offered for spending visiting periods hosted by project partners for scientific cooperation.
Job opportunities	Job opportunities are foreseen at national and international academic institutions, high-tech companies and SMEs involved in innovation and technical development sharing research with the Materials groups at PoliMi. Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared to Master of Science holders in the same field.
Composition of the research group	4 Full Professors 6 Associated Professors 2 Assistant Professors 10 PhD Students
Name of the research directors	Prof. Maurizio Vedani

Contacts
Phone: 02 2399 8230 Email: maurizio.vedani@polimi.it phd-dmec@polimi.it

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of 5401,42 euro.

Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). 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. 550 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.

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

THEMATIC Research Field: METAMATERIALS FOR CLOAKING AND ACOUSTIC STEALTH

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch,during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Acoustic cloaking refers to the possibility of making an obstacle neutral with respect to an incident sound. This is achieved by surrounding such obstacle with a layer of inhomogeneous and anisotropic material (called cloak) that guides acoustic waves around it, in such a way that the field outside the cloak remains as similar as possible to that obtained in the absence of the obstacle itself. By bending the acoustic rays in such a way that they never impinge onto the surface of the scatterer and that they come back onto their original trajectories, not only reflections are avoided, but also the shadow past the obstacle is erased. Such technology could have several interesting applications. The inhomogeneity and anisotropy required in the material properties required for cloaking make it impossible to realize it with conventional materials. For this reason, microstructured composites (also known as metamaterials) need to be engineered in such a way that their homogenized dynamic properties match the required ones in the frequency range of interest. Nowadays, experimental evidence of cloaking has been produced both in air and water in a bi-dimensional setting, i.e., when the obstacle is a circular or elliptical cylinder, and the incident wave propagates in the plane perpendicular to the axis of the obstacle. When dealing with a three-dimensional problem, the microstructure to be designed must be effective for every

	possible direction of propagation, and should thus present a 3D topology, that can be obtained only via 3D printing techniques. The first goal of the research activity, is thus to design, optimize, and experimentally test a 3D cloak. Moreover, when the relative motion between the fluid and the obstacle cannot be neglected (high Mach numbers) the standard design techniques of cloaking based on coordinate transformation fail because of the loss of invariance of the wave equation when the convective term is considered. However, it has been theoretically shown that a coordinate transformation in the space-time continuum can be used to design cloaks that work up to Mach 0.2. A second objective of the research activity is thus to improve the practicability of cloaks in presence of moving fluids.
Methods and techniques that will be developed and used to carry out the research	First, a method to systematically address the design of cloaks for simple three-dimensional geometries like spheres, or cylinders closed by hemispherical caps will be developed by using the tools of Transformation Acoustics. The dependence of acoustic performance on the design parameters (geometry of the obstacle, thickness of the cloak, overall mass constraints) will be evaluated too. More complicated geometries will be targeted instead with PDE-constrained optimization. Then, the 3D microstructure that implements the required material distribution must be designed. In this stage, algorithms for structural optimization will be developed to adjust the topology of the unit cells such that the long-wavelength equivalent material properties match those previously computed. Selective laser melting 3D printing will be used to fabricate the cloak, that will be then experimentally tested underwater to compute the reduction in target strength. Finally, new coordinate transformations will be investigated to address acoustic cloaking in presence of high Mach numbers.
Educational objectives	The challenges that the successful student will have to face are theoretical, numerical, and experimental. Among these, one can list: • development of suitable analytical models to compute the material properties required for cloaking;

	• implementation of coupled acoustic/structural numerical simulations to validate the effectiveness of the cloak when acoustic radiation is sent towards it; • deployment of structural optimization algorithms combined with numerical homogenization of microstructures to obtain the final geometry of the unit cell that make the cloak; • design of the experimental setup to validate the cloak in underwater acoustics;
Job opportunities	Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared Master of Science holders in the same field. The research is carried out in cooperation with several leading universities worldwide such as Imperial College London, ETH, and Harvard.
Composition of the research group	1 Full Professors 1 Associated Professors 1 Assistant Professors 2 PhD Students
Name of the research directors	Prof. Francesco Braghin

Contacts
Phone: +39 02 2399 8306 Email: francesco.braghin@polimi.it phd-dmec@polimi.it

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of 5401.42 euro. Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). Our candidates are strongly encouraged to spend a research period abroad, joining high-levelresearch 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. 550 euro/month- net amount). Teaching assistantship: availability of funding in recognition of supporting teaching activitiesby the PhD candidate. There are various forms of financial aid for activities of support to theteaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

INTERDISCIPLINARY Research Field: REAL-TIME OPTIMAL CONTROL AND MONITORING OF MECHANICAL STRUCTURES BY PDE CONSTRAINED OPTIMIZATION AND REDUCED ORDER MODELING

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch, during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Interdisciplinary PhD Grant The PhD research will be carried out in collaboration with research groups of the PhD programme in "**MATHEMATICAL MODELS AND METHODS IN ENGINEERING**". See https://www.dottorato.polimi.it/?id=422&L=1 for further information. Being able to solve optimal control and optimal design problems in real-time, for several virtual scenarios, requires rapid and reliable numerical methods that cannot rely on traditional high-fidelity, full order models (FOMs) such as the ones based on the finite element method. Two instances of relevant problems in this class are, for instance, the structural health monitoring (SHM) of vehicles/components by ultrasonic inspection to detect cracks in an early stage, and the design of (e.g., acoustic) cloaking devices. In the former case, the goal would be to design e.g. the geometry of the axles to maximize the performance of ultrasonic testing systems, ultimately identifying the presence of damage. In the latter, we rather aim at determining space-varying fields of material properties that nullify the scattered wave, after identifying

	the incident field from distributed measurements. In both cases, a double inverse problem has to be solved, in which a suitable cost functional that encodes the desired objective has to be minimized, subject to a set of physical constraints related to wave propagation, by acting on a control. This latter can be either the shape of the structure, as in the case of the SHM of the vehicle axles, or a space modulated density and bulk modulus in the cloaking region. This yields the solution of nonlinear optimal control problems governed by partial differential equations (PDEs). Moreover, to take into account different scenarios related to, e.g., loading conditions, vehicle motion, or material properties, a suitably parametrized version of the OCPs must be considered.The goal of the project is to analyse and numerically approximate nonlinear optimal control problems arising from the aforementioned applications, then performing experimental validation on mock-up structures. Algorithms for large-scale constrained optimization problems and reduced order modelling relying, e.g., on the reduced basis method for parametrized PDEs will be considered to enhance the numerical approximation of the physical models and solve the optimal control (or design) problems in almost real-time, for any new virtual scenario of interest.
Methods and techniques that will be developed and used to carry out the research	The project will combine techniques such as: PDE-constrained optimization and optimal control, reduced order modeling to replace high-fidelity FOMs for the efficient numerical approximation of parametrized differential problems and system identification. PhD candidates with a strong background in mathematical and numerical methods for engineering are therefore ideally positioned to carry out this project.
Educational objectives	The research aims at developing mathematical methods for the real-time optimal control and monitoring of mechanical structures exploiting PDE-constrained optimization and reduced order modelling.This research

	will tackle this task by advancing on four correlated objectives: 1. well-posedness analysis of nonlinear optimal control and shape optimization problems related with wave phenomena, and setting of a system of optimality conditions; 2. setting, analysis and implementation of rapid and reliable ROMs for the sake of computational efficiency, also paying attention to the definition of suitable shape parametrization in the case of optimal design, and the setting of material properties, aiming at finding the optimal implementable solution; 3. numerical approximation of double inverse problems, related with the identification of structural damages (for SHM problems) or the estimation of the incident field (for acoustic cloaking); 4. experimental validation on structural mock-ups of the structural designs obtained through numerical optimization.
Job opportunities	The primary job opportunity will be in the optimal control field, that is today required by almost any company that aims at minimizing costs and maximizing performance.Besides this, job opportunities will be with national and international academic and non-academic institutions and organizations, engaged in innovation, research, and technical development. Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared to Master of Science holders in the same field.
Composition of the research group	1 Full Professors 2 Associated Professors 4 Assistant Professors 0 PhD Students
Name of the research directors	Prof. Francesco Braghin, Prof. Andrea Manzoni ,

Contacts

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andrea1.manzoni@polimi.it

phd-dmec@polimi.it

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of 5401,42 euro.

Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). 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. 550 euro/month- net amount). Teaching assistantship: availability of funding in recognition of supporting teaching activitiesby the PhD candidate. There are various forms of financial aid for activities of support to theteaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

INTERDISCIPLINARY Research Field: SMART TECHNOLOGIES FOR VERTICAL AND PRECISION FARMING

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch,during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Interdisciplinary PhD Grant The PhD research will be carried out in collaboration with research groups of the PhD programme in "**MATERIALS ENGINEERING**". See https://www.dottorato.polimi.it/?id=422&L=1 for further information. The evolution of engineering disciplines and their implementation in agriculture has led, in recent years, to the development of systems and techniques for food production that could help solve some of the main problems in this sector. In this scenario, the birth of the concepts of vertical and precision farming was favored by the need to find a solution to the problems related to the exploitation of natural resources (soil and water), to have products at km0, to minimize the use of pesticides and to optimize production. However, the development in this sector is far from scientific and lacks a systematic approach that allows to consolidate the methods and techniques, thus favoring a real advancement of knowledge and a real implementation with results capable of justifying the use of these new technologies. The final goal of the research is therefore to formalize the problem associated with vertical farming techniques, propose and develop specific technologies for the sector, optimize

	processes and create a living lab in which experimentation can be carried out for the validation of the defined models.
Methods and techniques that will be developed and used to carry out the research	The methods implemented in the research will be theoretical (numerical and analytical) and experimental. The research will develop along 3 main research lines closely related to each other and which will concern: - the design and implementation of a sensorized and automated modular layout for vertical and precision farming; - the development and optimization of automation and product handling systems (e.g. soft picking) and control of the environment during the growth phases, also through the development of machine learning algorithms for the analysis of data relating to the conditions of plant growth and their properties; - the optimization of substrate and growth support materials (e.g. for the controlled release of H2O and nutrients). The strong interdependence of the research lines is evident, which will be adequately supported by experimental activities at the basis of the validation procedures of the models created and will allow a robust development of the identified technical solutions. The main result of the PhD activity will consist in the creation of a study platform and a small-scale laboratory in which to test innovative plant cultivation techniques, support the formalization of agronomic techniques for vertical farming and definition of optimal requirements. for plant engineering and materials associated with cultivation.
Educational objectives	PhD graduate will be able to have a interdisciplinary knowledge of technologies and processes related to new paradigms in agriculture, with a focus on automation, robotics for soft picking and new materials.
Job opportunities	Skills and competences in the field are extremely interesting for all the companies involved in vertical farming and new technologies for Agriculture. Our last

	survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared to Master of Science holders in the same field.
Composition of the research group	1 Full Professors 2 Associated Professors 4 Assistant Professors 6 PhD Students
Name of the research directors	Prof. Simone Cinquemani, Prof. Luigi De Nardo

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of 5401,42 euro. Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). 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. 550 euro/month - net amount).

Teaching assistantship: availability of funding in recognition of supporting teaching activitiesby 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.

POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

INTERDISCIPLINARY Research Field: TAILORED PIEZOELECTRIC MATERIALS AND OPTIMALLY DESIGNED METAMATERIALS FOR ENHANCED MECHANICAL ENERGY HARVESTING

Monthly net income of PhDscholarship (max 36 months)
€ 1325.0 In case of a change of the welfare rates or of changes of the scholarship minimum amount from the Ministry of University and Reasearch,during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Interdisciplinary PhD Grant The PhD research will be carried out in collaboration with research groups of the PhD programme in "**STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING**". See https://www.dottorato.polimi.it/?id=422&L=1 for further information. It has been recently demonstrated that introducing controlled porosity into the piezoelectric ceramic allows gaining relevant advantages for energy harvesting, compared to dense piezoelectric materials, due to the beneficial ratio between the piezoelectric coefficients and the permittivity. According to the results of the ERC project NEMESIS, completed in 2018, even better energy harvesting performance can be achieved in the case of layered piezoelectric materials where dense outer layers surround a highly porous sandwich layer: the longitudinal piezoelectric strain coefficient (d33) increases as the thickness of the porous layer and total porosity level of the layered structure. These preliminary results open new and interesting perspectives for the application of energy harvesting devices in the MEMS field but, to be able to optimize the harvester for this specific purpose, thorough

	research in the multi-physics and multi-scale modeling of these new materials as well as in the analysis of the powder synthesis route and shaping technology is required. The piezoelectric features can be suitably designed, harnessing the capabilities of innovative techniques of additive manufacturing. As a matter of fact, it is currently possible to create objects of complex shape, made of ceramic materials, both via binder jetting (powder -based additive manufacturing) and through inkjet printing. The research group has developed specific skills on such topics and may access to experimental equipment at the cutting edge of technology. The use of those machines, combined with a set of preliminary computational studies, may lead to the precise engineering of the porosity level, in order to achieve piezoelectric materials with unprecedented electro-mechanical features. The innovative piezoelectric materials can be applied to real devices for energy harvesting, also in view of recent research on the beneficial effect of metamaterials which are able to control the propagation of elastic waves. The research proposal aims at the optimal design of the metamaterial, so that the elastic energy can be focused on specific points, boosting the interaction with a piezoelectric resonator. The research group reached significant results in that field, but the shape optimization of the metamaterial is quite complicate. As a consequence, we plan to adopt the techniques of artificial intelligence, and more specifically of reinforcement learning, for the achievement of optimal metamaterials. In that way, the coupling of optimal metamaterials and innovative piezoelectric material may lead to interesting results in the ambit of vibration energy harvesting.
Methods and techniques that will be developed and used to carry out the research	The methods and techniques that will be used and further developed within this PhD are: • Selection of the lead-free material, the composition and the geometry of the final components • Simulation of the production processes, in order to forecast the final properties of the ceramic materials • Engineering of the microstructure through modeling of the functional properties in relation to porosity amount

	and morphology • Design of new energy harvesting architectures, with special focus on the optimal design of metamaterials via reinforcement learning • Production of ceramic samples by synthesis of the piezoelectric powder, cold consolidation of the complex structure by binder jetting @Funtasma Lab. (to control pore distribution and morphology, or generate porosity graded structures), densification • Study of the dispersion of nanosized powders to produce inks suitable for ink jet printing of MEMS devices with controlled porosity @Polifab • Test of the piezoelectric properties and correlation with the microstructural parameters Validation of the performance of the structures for mechanical energy harvesting and definition of the application parameters (frequency range, output energy etc).
Educational objectives	At the end of the PhD cycle the candidate will be able to define, design and carry out original research programs by working in a team or leading a research group in the field of smart materials. Opportunities will be offered for spending visiting periods hosted by project partners for scientific cooperation.
Job opportunities	All project activities are strongly connected to industrial needs and industrial and academic partners are directly participating to project tasks. Our last survey on MeccPhD Doctorates highlighteda 100% employment rate within the first year and a 35% higher salary, compared Master of Science holders in the same field.
Composition of the research group	0 Full Professors 2 Associated Professors 2 Assistant Professors 2 PhD Students
Name of the research directors	Prof. Nora Lecis, Prof. Raffaele Ardito

Contacts
Phone +39 02 2399 8283 Email: nora.lecis@polimi.it phd-dmec@polimi.it

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	662.5 €
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, funding for participation in courses, summer schools, workshops and conferences) for a total amount of 5401,42 euro.

Accommodation in Politecnico's Residences (http://www.residenze.polimi.it) is available for PhD candidates; special rates will be applied to selected out-of-town candidates (detailed info in the call for application). Our candidates are strongly encouraged to spend a research period abroad, joining high-levelresearch 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. 550 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.