dortmund university

Module handbook

Mechanics of Sustainable Materials and Structures (M.Sc.)

Multiple Degrees offered on a joint curriculum by

- Faculty of Architecture and Civil Engineering, TU Dortmund University (Germany)
- Department of Civil, Environmental and Mechanical Engineering, University of Trento (Italy)
- Department of Mechanics, Materials and Civil Engineering, Ecole Centrale de Nantes (France)

As of: October 2023

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General information on the degree program

University	TU Dortmund University (Germany) University of Trento (Italy) Ecole Centrale de Nantes (France)			
Location, if applicable				
Study programme (name/designation) incl. name changes, if applicable	Mechanics of Sustainable Materials and Structures (MS^2)			
Degree / degree title	Master of Science			
Form of study	Presence	x	Blended learning	☐
	Full-time	x	Intensive	☐
	Part-time	☐	Joint Degree	☐
	Dual	☐	Teaching profession	☐
	Part-time	☐	Combination	☐
	Distance learning	☐	Multiple Degree	x
Duration of studies (in semesters)	4			
Number of ECTS points awarded	120			
For Master's degree: consecutive or further education	Consecutive			
Commencement of studies on (date)	01.09.2024			
Admission capacity per semester / year (Max. number of students)	100			
Average number of first-year students per semester / year	20 per year (expected)			
Average number of graduates per semester / year	20 per year (expected)			

Goals / Learning outcomes of the study program

The Master Program « Mechanics of Sustainable Materials and Structures » is a multiple-degree diploma offered through joint training activities by TU Dortmund University (Germany), University of Trento (Italy) and Ecole Centrale de Nantes (France).

The master aims at training civil engineers as future leaders in developing innovative solutions for sustainability and performance in the built environment by fostering creative and independent thinking and promoting low-impact oriented problem solving.

This will be done by providing a solid background in fundamental mechanics coupled with cutting edge research on innovative materials and structures and with research and development environment in the private sector.

This cocktail of solid fundamental skills, innovative research and link to industry is the perfect environment to train engineers who are able to provide innovative solutions to the global today's challenges.

The degree program qualifies graduates for research related and technical professional activities in the fields of «advanced mechanics for innovative materials and structures», «materials and structures under extreme conditions» and « materials and structures in their environment ». It also trains students for PhD studies on advanced research topics involving the mechanics of materials and structures in the fields of Civil Engineering.

During their studies, students experience different forms of learning though diverse teaching methods: working alone and in groups, regular classes, exercises, laboratories, seminars, etc.

Due to the international character of the study program and the high degree of mobility, the inter-cultural dimension is particularly promoted in the formation of personality. During their studies, students not only exchange ideas with their own cohort, but also with local students of the three universities, thus gaining deep insight in the strengths underlying cultural exchanges.

General Information

If the principle of grammatical equal treatment of men and women is not always followed in the following, this is done for reasons of better readability. In all the contexts mentioned, the gender-specific designations used apply equally to women and men.

Examination regulations

Examination regulations for the master's degree in « Mechanics of Sustainable Materials and Structures » from 2023, valid from the start of the WS 2023/24.

Start of Studies

It is possible to start the course only in the winter semester.
The numbering of the different modules is given in the form 6 XX XX: the figure 6 refers to the fact that this Master program is the 6th educational program offered by the Faculty of Architecture and Civil Engineering at TU Dortmund University. The second figure (01, 02 or 03) refers to the semester at which the course takes place and the last figure indicates the consecutive numbering of the modules.

Workloads

Credits (CR): 1 CR corresponds to 30 working hours. The credits given for a module indicate the students the time required to achieve the goals of the module (e.g. 3 CR = 90 hours per semester). This time consists of the attendance time in the courses and the additional time required for the preparation and follow-up of the learning content, the completion of homework and the preparation for the exams. If a module is successfully completed, the associated credits are credited as credit points (ECTS).
Semester week hours (SWS): The SWS indicate the number of hours of a course per week. 1 SWS corresponds to 45 minutes.

Abbreviations

L: Lecture
E: Exercises
Lab: Laboratory
S: Seminar
T: Thesis

Module: Engineering Mathematics				6 01 01
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Engineering Mathematics	L + E	5	4

2 Course language
English

3 Teaching content
- Tensor Algebra (Cartesian coordinate frames, points, vectors, tensors, index notation, compact notation)
- Tensor Analysis (operations between tensors, eigenvalues and eigenvectors, principal invariants, differentiation, gradient, divergence, curl, Gauss' theorem)
- Short recap on Ordinary Differential Equations' solutions and integral calculus
- Partial differential equations of Mathematical Physics necessary for mechanics of sustainable materials and structures (heat transfer equation, wave equation, Navier-Stokes equation, mass transport equation, diffusion of pollutants in fluids, …)

4 Competencies
In the first part of the course, fundamental skills on tensor calculus and tensor analysis are acquired as a basis for all the subsequent mechanics-oriented courses.
Students learn to use both index and compact notations to perform operations between tensors which are the basic computational tools needed to address the modeling of all classical continuum and structural mechanical systems.
In the second part of the course, students learn the central concepts underlying the equations of Mathematical Physics as well as their applications in Engineering Science. Focus is given to PDEs which are of interest in the domain of Mechanics in Civil Engineering. The solution methods of PDEs which are given in this course provide a solid ground for all other Master program's courses.

5 Exams
Module examination: Written exam, oral exam, or homework with colloquium. (Form and extent of the examination will be determined at the beginning of the course)

6 Forms of examination
☒ Module Exam ☐ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor
Prof. Angela Madeo

Faculty in charge
Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: Advanced Continuum Mechanics				**6 01 02**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 8 ECTS	**Effort:** 240 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Advanced Continuum Mechanics	L + E	8	6

2 Course language

English

3 Teaching content

- Variational principles in mechanics (set of admissible displacements, virtual displacements, minimization of the Action Functional and Principle of Virtual Works)
- Applications : 1. motion of a particle, 2. rigid motions, 3. one-dim. deformable bodies
- Kinematics of a deformable continuum
- Reference configuration and material particles
- Eulerian (or current) configuration
- Lagrangian and Eulerian description of fields
- Homogeneous deformations, general deformations
- Strain tensors, deformation of volume and area
- Variational formulation of linear Cauchy elasticity
- Variational formulation of non-linear Cauchy elasticity in Lagrangian form
- First and second Piola-Kirchhoff stress tensors
- Constitutive equations (isotropy, invariance principles)
- Pull-back and push-forward operations (Piola transformations)
- Re-writing of the equations of motion in Eulerian form
- Cauchy stress tensor

4 Competencies

Building on the knowledge of Continuum Mechanics delivered in classical bachelor courses in Civil Engineering, the students learn alternative advanced tools (variational principles, principle of virtual works) to study the motion of classical mechanical systems like material particles, rigid bodies, one-dimensional deformable bodies.
In a second stage, special focus is given to the variational derivation of 3D Cauchy elasticity, both in the linear and non-linear case. In fact, while the study of linear mechanical systems is of fundamental importance to enable innovative solutions in engineering design, real systems often show non-linear responses under the application of certain mechanical loads. In the last part of this module, students learn to address the problem of the non-linear deformation of continuous elastic bodies thus becoming able to account for non-linear constitutive behaviors in the design of materials and structures.

5 Exams

Module examination: Written exam, oral exam, or homework with colloquium. (Form and extent of the examination will be determined at the beginning of the course)

6 Forms of examination

☒ Module Exam ☐ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master’s degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	**Faculty in charge**
Prof. Angela Madeo	Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: Enriched Continua and Metamaterials				**6 01 03**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Enriched Continua and Metamaterials	L + E	5	4

2 Course language

English

3 Teaching content

- Introduction to mechanical metamaterials (statics/dynamics)
- Negative Poisson materials, chiral materials, dispersion, band gaps, negative group velocity, Bragg-scattering, local resonance
- Bloch-Floquet analysis for periodic metamaterials (FEM implementation)
- Design and optimization of unit cells for passive noise and vibration control
- Conception of metamaterials' structures for elastic wave control enabling energy recovery
- Applications in Civil engineering
- Enriched continua (Micromorphic, micro-voids, etc.)
- Wave propagation in Cauchy continua, non-dispersive media
- Wave propagation in Enriched continua, dispersive media, band-gaps
- Continuum modeling of metamaterials for elastic wave control

4 Competencies

In the last decades the study of mechanical metamaterials is gaining growing attention due to the unprecedented applications that such new materials can provide.
Metamaterials are architectured materials that are able to show unorthodox static and dynamic properties thanks to their heterogeneous microstructure. Their use opens new perspectives for low-impact design of engineering structures, such as structures that can control elastic waves enabling more efficient energy conversion and recovery. Moreover, new 3d-printing techniques open perspectives to produce metamaterials with recycled polymers.
In this module, students learn to design mechanical metamaterials with unconventional mechanical properties (stretching in response to a compression load, band-gaps, dispersion, etc.) and to use them as building blocks for more complex structures with enhanced properties.
The mechanical behavior of metamaterials at large scales can be described through so-called enriched continuum models. Based on these models, students become capable of thinking about the modeling and design of new metamaterials' structures with unconventional properties with respect to wave propagation (dispersion, band-gaps, negative refraction). The possible use of metamaterials in engineering design strongly relies on solid knowledge in the advanced aspects of mechanics and wave propagation delivered in this module.

5 Exams

Module examination: Knowledge tests during the course and a project work (involving groups of 3 or more students)

6 Forms of examination

☐ Module Exam ☒ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor

Prof. Angela Madeo

Faculty in charge

Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: Nonlinear Structural Analysis				**6 01 04**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 6 ECTS	**Effort:** 180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Nonlinear Structural Analysis	L + E	6	2
2	Engineering with ANSYS	L + E		2

2 Course language
English

3 Teaching content
The mechanical parameters for the description of the component resistance are repeated and extended by plastic parameters. By generalizing the stress state, the plastic load capacity reserve can be explained and calculated for arbitrary cross-sections. For this purpose, various models for the interaction of internal forces are known and can be used. This is the basis for the determination of the plastic system reserve, which is applied within the framework of the yield joint theory. Thus, arbitrary beam systems can be analyzed with respect to ultimate load and deformation. The ultimate load sets as well as the methodology for unloading the system can be applied to various problems. In this way, increased demands on the structural safety, serviceability and durability of load-bearing structures can be assessed.
The above-mentioned analytical methods are deepened by the practical application of professional, CAD-supported programs. Flow zones in the beam and plastic load reserves are determined step-by-step and allow studies on the invariance of the ultimate load as well as on residual stresses after unloading. In this context, the extension to planar load-bearing elements is given and the application spectrum of the nonlinear calculation methodology is extended. The necessary program tools such as CAD component modeling and the organization of the calculation steps are dicussed and practiced in examples. This also includes the coupling of different structural elements as well as the parameter selection for mesh generation. Finally, for the analysis and evaluation of specific components, the formulation of contact between mechanical components is also discussed, applied in exercises and provided for the completion of a homework assignment.

4 Competencies
Students will be able to perform structural design based on nonlinear calculations in order to design structures efficiently and save material. This includes the prediction of the ultimate load as well as effects such as deformation and residual stress after unloading. In this way, the students prepare themselves for requirements in practice which, with a view to responsibility for people and the environment, pay attention to serviceability and durability.
The students know and use the potential of FEM simulations in engineering. By means of practical exercises, they are prepared to use CAD-supported software and can transfer these methods to other tasks. This also includes the use of innovative materials in civil engineering. Furthermore, construction elements can be analyzed which are not explicitly covered by classical methods or technical regulations, e.g. to develop new products.

5 Exams
Module examination: Written exam (120 min.)

6 Forms of examination
☒ Module Exam ☐ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Mandatory module – Master’s degree program in Mechanics of Sustainable Materials and Structures

9	**Module supervisor** Prof. Ingo Münch	**Faculty in charge** Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: Construction with Trees in Practice				6 01 05
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 3 ECTS	**Effort:** 90 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Construction with trees in practice	L + E	3	2

2 Course language
English

3 Teaching content
The subject explains the use of trees for the foundation of structures above the ground. The importance of forested areas in mitigating global problems such as climate change, species extinction, soil erosion and flood events is considered in this context, and concepts such as urban greening are addressed.
The content is structured as follows: Morphology of trees, compartmentalisation (Codit principle), wood strength, tree assessment and care: theory, equipment and practical measures, erection of structures in existing trees (construction process, risk assessment, risk reduction), design and planning of tree houses in practice, discussion and review of designs for practical construction projects, structural design, statics on the overall structure, dynamic analysis and vibration absorption.

4 Competencies
The students are familiar with the morphology, partitioning behaviour and assessment of supporting trees. They are able to incorporate the topic of construction botany into planning processes both theoretically and from experience with practical measures. The students also know the necessary instances for the construction of structures in tree populations. This also includes aspects of risk assessment and risk reduction in the state of construction. They are able to integrate static requirements into designs and to constructively design living structures. They have experience with modelling on the overall structure, which includes the elasticity and load-bearing capacity of the load-bearing trees. Furthermore, the students are familiar with the modal analysis for dynamic investigation as well as measures for vibration damping.

5 Exams
Module examination: Homework with colloquium

6 Forms of examination
☐ Module Exam ☒ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor
Prof. Ingo Münch

Faculty in charge
Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: "How sustainable can building materials be?"				**6 01 06**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 3 ECTS	**Effort:** 90 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	"How sustainable can building materials be?"	L + Lab	3	2

2 Course language
English

3 Teaching content
- Criteria for assessing the sustainability of building materials.
- Requirements for building materials and their characteristics.
- Trade-offs in the use of building materials.
- Getting to know the individual building materials and assessing them in the context of the different requirements (mineral building materials such as natural stones, artificial stones, mortars, concretes, clay and non-porous building materials such as glass, metal, polymers).
- Experimental work with different building materials in the laboratory (i.e. mechanical tests, recycling, re-use).

4 Competencies
Students learn to define requirements for building materials (mechanical, physical, durability, sustainability) and to evaluate their relevance in order to develop compromise solutions. This definition and consideration process is worked out for all relevant building materials and deepened by own experimental work in the laboratory.

5 Exams
Module examination: Knowledge tests during the course and a project work (involving groups of 3 or more students)

6 Forms of examination
☐ Module Exam ☒ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	**Faculty in charge**
Prof. Jeanette Orlowsky	Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: Structural Systems in Engineering Practices				6 01 07
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 1st semester	**Credits:** 3 ECTS	**Effort:** 90 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Structural Systems in Engineering Practices	L + E	3	2

2 Course language

English

3 Teaching content

- Maxwell's theorem for frame structures and its application in design
- Michell frames
- Graphical methods for optimal layout of truss systems
- Principal stress trajectories, force flow
- Sizing techniques for frames using energy methods
- Structural systems for high-rise and long-span structures
- Topology optimization: fundamentals, manufacturing constraints
- Form finding of cable nets (force density methods)
- Optimization of shells and grid shells
- Parametric Design
- Building Information Modelling BIM

4 Competencies

Students learn how to layout cross-material optimal, efficient and therewith sustainable structural systems using different techniques. This includes frames, shells, high-rise and long-span structures. Students will also get an introduction into parametric and computational design including building information modeling and management (BIM).

5 Exams

Module examination: 10% class participation, 30% homework, 30% midterm, 30% final exam

6 Forms of examination

☐ Module Exam ☒ Partial examination

7 Participation requirements

\- none -

8 Module type and usability of the module

Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	Faculty in charge
Prof. Christian Hartz	Faculty of Architecture and Civil Engineering, Technical University of Dortmund

Module: Organic Design and Structures 6 01 08

Master degree program: Mechanics of Sustainable Materials and Structures

Turnaround:	Duration:	Study section:	Credits:	Effort:
Annually at WiSe	1 semester	1st semester	3 ECTS	90 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Organic design and structures	S	3	2

2 Course language

English

3 Teaching content

The concept of organic building is defined from the different perspectives of architecture and civil engineering. In addition, the range of suitable materials, forms, structures and construction methods will be addressed. A practical building project is reviewed and the topics of the course are consolidated through individual work. One focus is on the material wood as well as the supporting element rope for the realization of hanging and/or prestressed structures. The constructive implementation with regard to inclusive building, sustainability and durability are an integral part of the self-work phase.

4 Competencies

The students are familiar with different definitions of organic building. They know different approaches and can apply them in the design as well as in the structural planning. They are also familiar with the overriding topics of building material extraction, building material processing, durability and inclusive building, in order to be able to accompany planning processes in a well-founded manner and with a view to sustainability.

5 Exams

Module examination: Student project followed by oral presentation with Q&A session

6 Forms of examination

☐ Module Exam ☒ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor

Jun. Prof. Dipl.-Ing. Anne Hangebruch
Prof. Ingo Münch

Faculty in charge

Faculty of Architecture and Civil Engineering,
Technical University of Dortmund

Module: Stability of Structures				**6 02 01**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at SuSe	**Duration:** 1 semester	**Study section:** 2nd semester	**Credits:** 6 ECTS	**Effort:** 180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Stability of Structures	L + E	6	4

2 Course language

English

3 Teaching content

- Introduction to the problem of instability
- Basics of Lyapunov theory
- Discrete conservative systems
- Continuous conservative systems (buckling of compressed columns, beam-column theory, buckling of plates)
- Numerical methods (Rayleigh-Ritz, Finite elements)
- Buckling collapse of frames
- Coupled flexural/torsional instability
- Lateral instability of beams
- Basics of the “elastica”
- Non-conservative systems (divergence and flutter via follower loadings, parametric resonance for non-stationary loadings)

4 Competencies

The course is focused on various instability phenomena that may involve both isolated structural elements and structures as a whole (collapse due to instability of frames or arches), which the designer of structures should be aware of, especially when faced with light structures. At the end of the course the student will be able to: (i) understand and interpret the various types of structural instability with particular reference to conservative and non-conservative systems; (ii) calculate the critical load and analyze the post-critical behavior of discrete structures; (iii) apply non-linear second-order structural analysis for calculating the critical load / limit load of single beams, plates and beam systems; (iv) apply numerical methods (Rayleigh-Ritz and Finite Elements) for the approximate calculation of the critical load of slender structures. With a change of paradigm, the concepts delivered in this course not only guide the classical design approach aimed at avoiding instabilities, but also represent the key for designing instability-based mechanisms to be exploited in innovative energy harvesting and vibration mitigation devices.
With a change of paradigm passing from buckliphobia to buckliphilia, the concepts delivered in this course not only guide the classical design approach aimed at avoiding instabilities, but also represent the key for designing instability-based mechanisms to be exploited in innovative energy harvesting, allowing for collecting energy from environmental events, and vibration mitigation devices, and for protecting structures and infrastructures.

5 Exams

Module examination: Homeworks and presentation (involving groups of 3 or more students)

6 Forms of examination

☐ Module Exam ☒ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master’s degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	**Faculty in charge**
Prof. Francesco Dal Corso	

Module: Stability of Structures		6 02 01
		Department of Civil, Environmental and Mechanical Engineering, University of Trento

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<tr><td colspan="2">Turnaround:
Annually at SuSe</td><td>Duration:
1 semester</td><td>Study section:
2nd semester</td><td>Credits:
6 ECTS</td><td colspan="2">Effort:
180 h</td></tr>
<tr><td rowspan="3">1</td><td colspan="6">Module structure</td></tr>
<tr><td>No.</td><td colspan="2">Element / Course</td><td>Type</td><td>Credits</td><td>SWS</td></tr>
<tr><td>1</td><td colspan="2">Modeling and Simulation of Structures</td><td>L</td><td>6</td><td>4</td></tr>
<tr><td>2</td><td colspan="6">Course language
English</td></tr>
<tr><td>3</td><td colspan="6">Teaching content
Finite element method for advanced structural applications: structural elements (beams, plate and shells), coupled problems, thermoelasticity, nonlinear elasticity, plasticity, visco-plasticity, structural dynamics, coding of constitutive models in a user material subroutine, practical use of commercial and open source finite element programs. Practical examples of constitutive models for ceramic forming and refractories at high temperatures. Design optimization towards reduction of material and energy waste.</td></tr>
<tr><td>4</td><td colspan="6">Competencies
The course provides the necessary tools to effectively apply the theoretical models in the FEM simulation of structures, even in advanced contexts (material and geometric non-linearities, dynamic conditions, coupling with other physical phenomena). The objective is to make the student capable of: formulating an adequate model of the structural problem under examination and expressing it in a weak form suitable for the discretization of the model; knowing the fundamental steps for the discretization and implementation of the model in a computational code; interpret and evaluate the results provided by a computational simulation; use open source and commercial computational tools as a means for designing, analyzing and optimizing structures. In addition to the purely operational aspect, the student will acquire the critical ability that allows the civil engineer to conceive, build and interpret a computational model.
Mechanical modeling and numerical simulation drive the design optimization of structural components towards maximizing the bearing capacity and minimizing the environmental footprint through the reduction of material volume/weight.</td></tr>
<tr><td>5</td><td colspan="6">Exams
Module examination: Project (involving groups of 3 or more students)</td></tr>
<tr><td>6</td><td colspan="6">Forms of examination
☒ Module Exam ☐ Partial examination</td></tr>
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- none -</td></tr>
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Mandatory module – Master’s degree program in Mechanics of Sustainable Materials and Structures</td></tr>
<tr><td>9</td><td colspan="3">Module supervisor
Prof. Andrea Piccolroaz</td><td colspan="3">Faculty in charge
Department of Civil, Environmental and Mechanical Engineering,
University of Trento</td></tr>
</table>

Module: Mechanics of Solids and Structures under Extreme Conditions — 6 02 03

Master degree program: Mechanics of Sustainable Materials and Structures

Turnaround:	Duration:	Study section:	Credits:	Effort:
Annually at SuSe	1 semester	2nd semester	6 ECTS	180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Mechanics of Solids and Structures under Extreme Conditions	L + E	6	4

2 Course language
English

3 Teaching content
- Mechanics of moderate to extreme deformations: a review;
- Cellular solids as mitigators of the effects of extreme loadings: elastic and inelastic behavior of natural and architected materials;
- High-stress concentrations and fracture in cellular solids: toughness design;
- Impact and explosion on cellular cladding shielding structures: the order zero design;
- A glimpse on wave attenuation + time-dependent effects for mitigating extreme loading effects;
- Laboratory experience on 3D printing of architected materials and mechanical testing

4 Competencies
Mastering the approaches suitable to capture the nonlinearities exhibited by architected solids and structures under extreme events is key for analyzing and designing sustainable systems under situations that cannot be captured through standard methodologies.
The bulk of the course will be the exploitation of the mechanical properties of cellular solids, both natural and architected, produced through 3D printing, as sustainable mitigating media for extreme loadings. The first part of the course deals with a review of large deformation mechanics of deformable bodies. A thorough journey on the mechanics of natural and sustainable artificial cellular solids will then be offered in the bulk of this course. Both reversible and irreversible regimes of polymeric, metallic and ceramic honeycombs, structural foams, and architected materials undergoing severe compression, tensile loadings and shearing will be addressed. Fracture mechanics will also be utilized for analyzing toughness of cellular and architected structures. Finally, medium-to-high and extreme rate effects of loadings will be analyzed, and zero order design concepts and criteria for mitigating impacts and blasts on structures shielded by cellular claddings will be delivered.
The mechanics of natural and sustainable architected materials is addressed encompassing concepts and criteria for mitigating impacts and blasts on structures.

5 Exams
Module examination: Exam testing students on one or more topics of their choices (among the ones treated within the course).

6 Forms of examination
☒ Module Exam ☐ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor
Prof. Luca Deseri

Faculty in charge
Department of Civil, Environmental and Mechanical Engineering,
University of Trento

Module: Machine Learning for Wireless Structural Health Monitoring 6 02 04

Master degree program: Mechanics of Sustainable Materials and Structures

Turnaround:	Duration:	Study section:	Credits:	Effort:
Annually at SuSe	1 semester	2nd semester	6 ECTS	180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Machine Learning for Wireless Structural Health Monitoring	L + E	6	4

2 Course language

English

3 Teaching content

This module covers the fundamental concepts on the theory and methods of machine learning (ML) and its application to the wireless structural health monitoring (SHM) with a focus on sustainable materials and structures. Towards this aim, the teaching activities comprise a fruitful alternation between the following didactic modalities:

- Theoretical lessons on the fundamental ML concepts and methodologies for the efficient and robust solution of both classification and regression problems, with a focus on three-steps learning-by-examples strategies effectively integrating space reduction, sampling, and prediction techniques (40% of the timetable).
- Software classes aimed at enriching the students' competences learned from the theoretical lessons through hands-on sessions where several ML methodologies are implemented and tested (40% of the timetable).
- Overview of innovative ML techniques as applied to SHM problems (20% of the timetable).

4 Competencies

Students learn the fundamental theoretical concepts of ML and understand the main differences between several state-of-the-art ML methodologies in terms of underlying mathematical background and range of applicability. Moreover, they learn how to analyze the data collected by wireless sensors as well as how to extract from them highly-informative low-dimensionality features which can be exploited to build prediction/surrogate models. They also understand how to develop accurate and fast models that can be used for the identification, localization, and quantification of damages in sustainable materials and structures. Finally, they acquire competences on how to apply and customize several ML techniques to real-world problems related to wireless SHM as well as to evaluate the accuracy and reliability of the generated surrogate models.

The use of machine learning for wireless structural health monitoring plays an important role in ensuring the sustainability of civil infrastructures, by helping to detect and prevent damage and deterioration, and by enabling more efficient and sustainable design, maintenance, and repair practices to increase their lifetime.

5 Exams

Module examination: Written exam (120 min.) and project (involving groups of 3 or more students)

6 Forms of examination

☐ Module Exam ☒ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor

Prof. Marco Salucci

Faculty in charge

Department of Civil, Environmental and Mechanical Engineering,

		University of Trento

Module: Metastructures 6 02 05

Master degree program: Mechanics of Sustainable Materials and Structures

Turnaround:	Duration:	Study section:	Credits:	Effort:
Annually at SuSe	1 semester	2nd semester	6 ECTS	180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Metastructures	L + E	6	4

2 Course language

English

3 Teaching content

- Electromagnetic Waves and properties. Maxwell's equations and the electromagnetic (EM) wave equation
- Waves and Metamaterials. Plane Waves in Homogeneous Media. The Generalized Snell's law to wave control in EM systems
- Periodic and Quasi-Periodic EM Metastructures
- Discrete one-, two- and three-dimensional metastructures
- Bloch waves in origami metamaterials and cloaking transformation in elastic plates
- Techniques for scattering reduction of flexural waves propagation
- Random field approaches for metamaterials in presence of uncertainties
- Stochastic spectral approaches for random inputs
- Passive control, linear and nonlinear metastructures
- Life cycle assessment and sustainable metastructures

4 Competencies

Nowadays, the demand for more broadband and multiband operability is increasing both in electronic and mechanical applications, and deflecting, absorbing and/or mitigation vibration capabilities of materials and structures are required to go hand in hand with this demand. Along these veins, periodic and quasi-periodic materials and structures, i.e. metamaterials and metastructures, have not only promised to exhibit extraordinary wave control properties, but have proven in many cases to be more tunable to applications' operational frequency ranges, to be potentially more adaptable to applications' requirements, and to possess a number of functional and structural advantages with respect to conventional materials and structures.In this module, students can acquire the basic properties of electromagnetic (EM) fields and waves and how EM metamaterials and periodic 2D and 3D artificial structures interact with wireless propagation. Moreover, mechanical analysis and design of 2D and 3D mechanical metastructures are reviewed, and their mechanical behavior and deformation mechanisms are investigated through force and momentum equilibrium principle, strain energy analysis and homogenization theories. Afterwards, multifunctional properties of mechanical metamaterials are elaborated, such as vibration attenuation, bandgap features and impact energy absorption. In addition, metastructures endowed with resonators are taught, that have proven to inherit valuable properties from wave propagating in phononic periodic structures in the very low-frequency regime. In this context, both the impact of massive resonators with varying frequencies and devices with nonlinear and hysteretic behavior enhance the whole system performance. Emphasis is placed on modeling both the stochastic nature of input loading and the inherent variability of material and geometric properties. Finally, life cycle assessment tools capable of evaluating embodied carbon metrics and global warming potentials (GWPs) of the examined class of metastructures are taught.

Life cycle assessment tools capable of evaluating embodied carbon metrics and global warming potentials (GWPs) of the examined class of metastructures are taught.

5 Exams

Module examination: Discussion on the project (involving groups of 3 or more students)

6 Forms of examination

☐ Module Exam ☒ Partial examination

7 Participation requirements

	- none -	
8	**Module type and usability of the module** Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures	
9	**Module supervisor** Prof. Oreste Bursi	**Faculty in charge** Department of Civil, Environmental and Mechanical Engineering, University of Trento

Module: Risk Analysis and Structural Reliability				**6 02 06**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at SoSe	**Duration:** 1 semester	**Study section:** 2nd semester	**Credits:** 6 ECTS	**Effort:** 180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Risk analysis and structural reliability	L + E	6	4

2 Course language

English

3 Teaching content

- Review of Linear Algebra by introducing Principal Component Analysis
- Basic Probability Theory (Principles of measure theory, Random variables, Bayesian Probability, Copula theory and dependencies models)
- Random processes (Poisson Processes, Markov Processes, Random fields)
- Structural Reliability (Formulation of Reliability and Structural Reliability problem, Reliability index, First-Order Reliability Methods, HLRF algorithm (constraint optimization for structural reliability problems), Second-Order Reliability Methods, Sensitivity analysis with respect to the reliability, Structural system reliability)
- Monte Carlo methods (Classical Monte Carlo Methods, Importance Sampling Methods, Markov Chain Monte Carlo for rare event estimation (Subset simulation), Markov Chain Monte Carlo for Bayesian inversion
- Metamodeling for rare event estimation -optional- (Equivalent linearization, Gaussian Process metamodels)

4 Competencies

This course is designed to provide students with a comprehensive understanding of probability theory, statistics, risk analysis, and reliability theory as they relate to sustainable structures (and infrastructures) and, more generally, to civil engineering problems. The objective of the course is to expose students to the various uncertainties that impact engineering decisions and equip them with the necessary tools to model and analyze these uncertainties in the context of engineering risk assessment.

The course will begin by introducing the fundamentals of probability theory and statistics and will progressively build upon them. The focus will be on probabilistic modeling and analysis of civil and environmental engineering problems, Bayesian statistics, risk analysis, and decision-making under uncertainty. Particular attention is given to Structural Reliability, which is essential to assess structural safety of existing and novel structure of infrastructures.

The course will cover the following topics: a review of linear algebra by introducing Principal Component Analysis (PCA), basic Probability Theory for modeling uncertainties, dependencies modeling via Copula theory, First Order Reliability Methods, Sensitivity methods, Monte Carlo methods, Markov Chain Monte Carlo Methods. With a solid foundation in these concepts, students will be well-prepared to make informed decisions and assess risk in the field of civil engineering with a particular focus on sustainable structures.

To design structures and infrastructures that are safe, reliable, sustainable, and environmentally responsible, engineers must employ a comprehensive approach that incorporates risk analysis, structural reliability methods, and sustainable design and management practices. These critical tools enable engineers to identify potential hazards and evaluate the likelihood of failure while also considering the long-term environmental impact and resource consumption of their designs. This approach not only benefits the environment but also contributes to cost savings over time, as efficient and sustainable systems typically require less maintenance and resource use. Therefore, the implementation of risk analysis, structural reliability methods, and sustainable design and management practices is essential for engineers seeking to create a better, more sustainable future.

5 Exams

Module examination: Homework with final symposium

Module: Risk Analysis and Structural Reliability			6 02 06
6	**Forms of examination** ☐ Module Exam	☒ Partial examination	
7	**Participation requirements** - none -		
8	**Module type and usability of the module** Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures		
9	**Module supervisor** Prof. Marco Broccardo	**Faculty in charge** Department of Civil, Environmental and Mechanical Engineering, University of Trento	

Module: Mechanics of Porous Media				**6 03 01**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Mechanics of Porous Media	L + E	5	4

2 Course language

English

3 Teaching content

Introduction to the kinematics of porous media. Thermodynamics and fluid transfer. Thermal effects. Saturated/partially saturated porous media. Thermo-hydro-mechanical constitutive laws. Poroelasticity. (Poro-)plastic models of sands and clays. (Poro-)viscoelasticity. Case studies.

Bibliography:

- O. Coussy Poromechanics 2004 Wiley
- O. Coussy Mechanics and Physics of Porous Solids 2010 Wiley
- L. Dormieux, E. Bourgeois Introduction à la micromécanique des milieux poreux 2002 Presses Ecole National des Ponts et Chaussées
- L. Dormieux, D. Kondo, F.J. Ulm Microporomechanics 2006 Wiley

4 Competencies

The course covers the characterization of constitutive laws of porous media addressing both the behavior of natural materials (as soils and rocks) and concrete. In particular a thermo-hydro-mechanical approach is proposed to account for the coupling between classical solid continuum mechanics, mechanics of multi-phase fluids and thermal effects. Competences in this domain are of paramount importance in the sustainable management of energy resources (e.g. the underground storage of CO_2 or of hydrocarbons/hydrogen synthesized from renewable energies or geothermal energy exploitation), in the thermal improvement of building materials (for reducing energy bills and greenhouse gas emissions) or in the protection against natural hazards (e.g. coastal erosion, landslides, floodings). Examples will be provided to coarsely describe some of the environmental issues that can be tackled by the acquired knowledge.

5 Exams

Module examination: Written exam (120 min.)

6 Forms of examination

☒ Module Exam ☐ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	**Faculty in charge**
Prof. Giulio Sciarra	Mechanics, Materials and Civil Engineering Department, École centrale de Nantes

Module: Homogenization Methods for Materials and Structures				**6 03 02**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Homogenization Methods for Materials and Structures	L + E	5	4

2 Course language

English

3 Teaching content

Microstructural descriptors: n-Point Probability Functions, ensemble averages, ergodic hypothesis and statistical homogeneity, scale separation, notion of the Representative Volume Element (RVE).

Averaging operations, concentration and homogenization: uniform stress (strain) boundary conditions. Hill Lemma. Reuss and Voigt bounds.

Classical homogenization schemes for elastic and poroelastic materials.

Asymptotic expansion method for linear homogeneous elastic structures: beams and plates. Justification of the Euler-Navier-Bernoulli and Love-Kirchhoff models.

Double-scale expansion and periodic homogenization. Applications to the study of incompressible Newtonian fluid flow through a rigid porous medium (the Darcy law) and quasi-statics of saturated deformable porous media.

Homogenization of periodic heterogeneous beams.

Practical projects: (i) numerical homogenization of heterogeneous materials, (ii) numerical solution of the homogenization problem for a periodic beam using Abaqus.

Bibliography

- J.L. Auriault et al. Homogenization of Coupled Phenomena in Heterogeneous Media. (2009) Wiley
- P.G. Ciarlet. Mathematical Elasticity - Volume II : Theory of Plates. Studies in mathematics and its applications. – North-Holland, Amsterdam, 1997
- L. Dormieux, D. Kondo, F.J. Ulm Microporomechanics. (2006) Wiley
- T. Kanit et al. Determination of the size of the representative volume element for random composites: statistical and numerical approach. Int. J. Solids Structures 40 (2003) 3647- 3679
- T. Lewinski, J.J. Telega. Plates, laminates and shells: asymptotic analysis and homogenization, Vol. 52. World Scientific, 2000.
- S. Torquato Random Heterogeneous Materials (2002) Springer
- L. Trabucho, J.M. Viano. Mathematical Modelling of Rods. Handbook of Numerical Analysis, ed. par P.G. Ciarlet et J.L. Lions. pp. 487–974. North-Holland, Amsterdam, 1996.

4 Competencies

The course deals with the characterisation of the behavior of heterogeneous materials, eventually (saturated) porous materials, and slender structures by means of upscaling methods. Upscaling techniques allow to estimate equivalent constitutive properties of a continuum describing the deformation of a body using an average coarse formulation which stems from the knowledge of the characteristics of a more refined one. Examples are ubiquitous in materials & structures of civil engineering, as for instance granular materials, beam, shell and masonry structures, but also metamaterials, where the micro-structure designed to achieve a specific goal is homogenized into average macro-scale constitutive parameters.

The competences achieved will be of paramount importance in the comprehension of the response of materials with micro-structure, to be designed or exploited in building optimization and management of renewable energy resources, and in the design of low-impact structures in response to complex loadings.

5 Exams

Module examination: Hands-on project (with report (nvolving groups of 3 or more students) and written exam (120 min.)

Module: Homogenization Methods for Materials and Structures		6 03 02
6	**Forms of examination** ☐ Module Exam ☒ Partial examination	
7	**Participation requirements** - none -	
8	**Module type and usability of the module** Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures	
9	**Module supervisor** Prof. Giulio Sciarra	**Faculty in charge** Mechanics, Materials and Civil Engineering Department, École centrale de Nantes

Module: Coupled Problems in Mechanics: from Mathematical Formulation to Numerical Methods				**6 03 03**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 6 ECTS	**Effort:** 180 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Coupled problems in mechanics: from mathematical formulation to numerical methods	L + E	6	4

2 Course language

English

3 Teaching content

The course will present and discuss various computational approaches for the numerical simulation of coupled problems. The first part of the course will consider the problem from the abstract point of view of coupled systems. We will identify and describe:
- the various classes of coupled problems (weak vs. strong coupling),
- the various classes of algorithmic approaches (monolithic, staggered, sequential),
- the problems and difficulties linked to field transfer.

Emphasis will be put on notions of physical and numerical stability.
In the second part of the course, these concepts will be put into practice for specific types of coupled problems, such as thermo-mechanics or poro-mechanics.
A particular emphasis will be placed on variational approaches. Variational approaches consist in formulating the problem as an optimization problem (on unknown fields), and constitute a fundamental basis in numerical approximation methods, such as finite elements.
This second part of the course will be organized as follows:
- review of variational formulations in solid mechanics and heat transfer
- time-continuous variational formulations for coupled problems
- time-discrete (incremental) variational formulations for coupled problems
- examples in thermo-mechanics and poro-mechanics

Bibliography:

- D.E. Keyes et al., Multiphysics simulations: Challenges and opportunities, International Journal of High Performance Computing Applications 27: 4 (2013).
- L. Stainier, A Variational Approach to Modeling Coupled Thermo-Mechanical Nonlinear Dissipative Behaviors, Advances in Applied Mechanics 46:69-126 (2013).

4 Competencies

- knowledge and understanding of: challenges of coupled problems in numerical simulation, broad classes of coupled problems, different algorithmic approaches which are used in practice, their relative advantages and associated difficulties;
- an ability to: identify and classify coupled problems of various types, identify sources and mechanisms of coupling and their implication from a computational viewpoint; formulate an adapted algorithmic strategy for practical coupled problems and translate the formulation to a practical computational approach using existing tools as much as possible; study independently; use library resources; solve coupled problems with finite element code(s).
- knowledge and understanding of: what is a variational formulation in field theories of physics; challenges in formulating coupled problem variationally; the relations between variational formulations and approximation methods; available variational formulations in thermo-mechanics and poro-mechanics;
- an ability to: exploit variational formulations to derive approximate solutions (FE, Galerkin, limit analysis); use the variational structure of a problem to derive stable numerical methods.

These competences are propaedeutic to the study of strongly coupled problems describing the behavior of (geo)structures under environmental conditions. In the context of lifetime extension and vulnerability reduction these typically arise in land vulnerability assessment and natural risk prevention, while in management of energy resources in underground storage of energy and CO_2.

Module: Coupled Problems in Mechanics: from Mathematical Formulation to Numerical Methods		**6 03 03**
5	**Exams** Module examination: Hands-on project (with report involving groups of 3 or more students) and written exam (120 min)	
6	**Forms of examination** ☐ Module Exam ☒ Partial examination	
7	**Participation requirements** - none -	
8	**Module type and usability of the module** Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures	
9	**Module supervisor** Prof. Laurent Stainier	**Faculty in charge** Mechanics, Materials and Civil Engineering Department, École centrale de Nantes

Module: Design and Behavior of Modern Concrete				6 03 04
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Design and Behavior of Modern Concrete	L + E	5	4

2 Course language

English

3 Teaching content

Cement hydration. Cement hydration in the presence of mineral additives. Physical consequences of cement hydration. Microstructure of the cement paste. Delayed behavior of concrete: shrinkage and creep. Theoretical basis for the formulation of concrete. Basics of the formulation of modern concrete, quantification of their environmental impact. Fracture mechanics of concrete. Advanced experimental methods.

4 Competencies

The aim of the course is to provide knowledge of the physical, chemical and mechanical properties of materials used in the composition of concrete. Skills in practices of concrete formulation are provided to attain a target performance with respect to the mechanical behavior of the material and lifetime extension measured by its durability.

5 Exams

Module examination: Written exam (120 min.)

6 Forms of examination

☒ Module Exam ☐ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master’s degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	Faculty in charge
Prof. Ahmed Loukili	Mechanics, Materials and Civil Engineering Department, École centrale de Nantes

Module: Modern Languages				**6 03 05**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 2 ECTS	**Effort:** 60 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Modern Languages	L	2	2

2 Course language

French (and English)

3 Teaching content

Full range of practical communication language exercises: reading comprehension, listening comprehension, written expression, oral expression.
Students will be able to use the foreign language in a simple way for the following purposes: giving and obtaining factual information as personal and non-personal information, establishing and maintaining social and professional contacts, carrying out certain transactions.

4 Competencies

The objective is to familiarize the learner with the French language and French culture through an entertaining task-based communicative language teaching, focused on speaking combined with: phonetics, learning lab activities, project work, tutoring. Course objectives include the acquisition and reinforcement of vocabulary, syntax, and pronunciation by both traditional means and through the use of digital resources.
After completing this course, the students will be able to communicate in spoken and written French, in a simple, but clear manner, on familiar topics in the context of study, hobbies etc. Another important goal of the course is to introduce the student to French culture.

5 Exams

Module examination: Written exam (120 min.)

6 Forms of examination

☒ Module Exam ☐ Partial examination

7 Participation requirements

- none -

8 Module type and usability of the module

Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor

Silvia Ertl

Faculty in charge

Mechanics, Materials and Civil Engineering Department,
École centrale de Nantes

Module: Summer School				**6 03 06**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 2 ECTS	**Effort:** 60 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Summer School	L	2	-

2 Course language
English

3 Teaching content
This one-week school includes Faculty lectures on current advances in the mechanics of sustainable materials and structures, as well as lectures from experts of the private sector, *e.g.*, lectures from the non-university associated partners and from alumni of the study program.

4 Competencies
The students experience an unconventional cocktail of training on solid fundamental skills, innovative research, link to the private sector and inter-cultural exchange. This provides the perfect environment not only to train engineers who are able to provide innovative solutions to the global today's challenges, but also to prepare the perfect ground for an informed choice on the Master Thesis subject.

5 Exams
Module examination: Attendance (no grading)

6 Forms of examination
☐ Module Exam ☐ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor
Prof. Giulio Sciarra

Faculty in charge
Mechanics, Materials and Civil Engineering Department,
École centrale de Nantes

Module: Durability and Structural Maintenance				**6 03 07**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Durability and Structural Maintenance	L + E	5	4

2 Course language
English

3 Teaching content
Sustainability indicators. General approach of Durability of concrete against corrosion, sulfate attack, alkali aggregates reaction, frost. Permeability. Chloride Diffusion. Carbonation. Mechanisms involved during chloride ingress (chloride binding, electrostatic interaction, Electrical Double Layer). Performance-based approach to concrete durability. Non-Destructive-Testing and maintenance.

4 Competencies
Concrete is the most consumed and used material in the world. It is considered in the absence of precautions as a material polluting the atmosphere because of the large amount of CO_2 emitted during the calcination of clay and limestone. Concrete structures must therefore be not just well dimensioned to achieve the envisaged bearing capacity, but they must be durable too. Studying the durability of concrete structures is therefore the good way to limit CO_2 emissions and dispersion of other harmful products for the environment.
Competences are transferred on the use of sustainability indicators, as permeability and diffusivity of chemical species, within the framework of sophisticated models of coupled transfers of chemical species. A performance approach to sustainability of structures is discussed based on the formulation of concrete for an expected lifespan in a given environment. Non-destructive testing skills are also provided to monitor life of structures and calibrate the models to evaluate their durability.

5 Exams
Module examination: Hands-on project (with report involving groups of 3 or more students) and written exam (120 min)

6 Forms of examination
☐ Module Exam ☒ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Elective module – Master's degree program in Mechanics of Sustainable Materials and Structures

9 Module supervisor
Prof. Abdelhafid Khelidj

Faculty in charge
Mechanics, Materials and Civil Engineering Department,
École centrale de Nantes

Module: Earthquake Engineering				**6 03 08**
Master degree program: Mechanics of Sustainable Materials and Structures				
Turnaround: Annually at WiSe	**Duration:** 1 semester	**Study section:** 3rd semester	**Credits:** 5 ECTS	**Effort:** 150 h

1 Module structure

No.	Element / Course	Type	Credits	SWS
1	Earthquake Engineering	L + E	5	4

2 Course language
English

3 Teaching content
Part I - Dynamics of structures – Seismic risk and seismic hazard; dynamic equation of a simple oscillator, dynamic equation of a multi-degree-of-freedom structure; modal analysis, modal superposition technique, modal spectrum analysis. Earthquake-resistant structure design according to EC8, capacity design. Nonlinear calculations. Introduction to nuclear plant design.
Part II - Soil dynamics and geotechnical earthquake engineering – Dynamic soil properties: ground motion parameters, wave propagation, ground response analysis, soil liquefaction, seismic slope stability, seismic design of foundations
Bibliography:
- A.K. Chopra, Dynamics of Structures, Theory and Applications to Earthquake Engineering, second edition, Prentice-Hall, 2001.
- M. Géradin and D. Rixen, Mechanical vibrations. John Wiley and Sons, 1997.
- S.L. Kramer, Geotechnical Earthquake Engineering, Prentice-Hall, 1996.

4 Competencies
The purpose of the course is to raise students' awareness of the seismic risk, learn to analyze the dynamic behavior of a structure, providing the general principles of earthquake-resistant design. In particular the proper choice of safety factors is framed in the context of sustainable engineering in order to cut down unnecessary strain on resources, which in turn affects future generations. An energy-conscious and performance based improved design of structures is therefore proposed based on the critical adoption of new design procedures.

5 Exams
Module examination: Written exam (120 min.)

6 Forms of examination
☒ Module Exam ☐ Partial examination

7 Participation requirements
- none -

8 Module type and usability of the module
Elective module – Master’s degree program in Mechanics of Sustainable Materials and Structures

9

Module supervisor	**Faculty in charge**
Prof. Panagiotis Kotronis	Mechanics, Materials and Civil Engineering Department, École centrale de Nantes

Module: Master Thesis						**6 04**
Master degree program: Mechanics of Sustainable Materials and Structures						
Turnaround: Annually at WiSe		**Duration:** 1 semester	**Study section:** 4th semester		**Credits:** 30 ECTS	**Effort:** 900 h
1	**Module structure**					
	No.	**Element / Course**		**Type**	**Credits**	**SWS**
	1	Thesis		T	30	-
2	**Course language** English					
3	**Teaching content** Depending on the master thesis subject.					
4	**Competencies** Students are able to approach new topics independently, have in-depth knowledge of specific scientific methods and their applications, and are able to analyze and verify research results.					
5	**Exams** See Examination regulations.					
6	**Forms of examination** ☒ Module Exam ☐ Partial examination					
7	**Participation requirements** See Examination regulations.					
8	**Module type and usability of the module** Mandatory module – Master's degree program in Mechanics of Sustainable Materials and Structures					
9	**Module supervisor** Prof. Angela Madeo Prof. Ingo Münch Prof. Francesco Dal Corso Prof. Giulio Sciarra			**Faculty in charge** - Faculty of Architecture and Civil Engineering, Technical University of Dortmund - Department of Civil, Environmental and Mechanical Engineering, University of Trento - Mechanics, Materials and Civil Engineering Department, École centrale de Nantes		