Course guide
295103 - 295II013 - Simulation and Optimisation

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Unit in charge:	Barcelona East School of Engineering
Teaching unit:	749 - MAT - Department of Mathematics. 737 - RMEE - Department of Strength of Materials and Structural Engineering. 751 - DECA - Department of Civil and Environmental Engineering.
Degree:	MASTER'S DEGREE IN INTERDISCIPLINARY AND INNOVATIVE ENGINEERING (Syllabus 2019). (Compulsory subject). MASTER'S DEGREE IN RESEARCH IN MECHANICAL ENGINEERING (Syllabus 2021). (Optional subject).

Academic year: 2025 **ECTS Credits:** 6.0 **Languages:** English

LECTURER

Coordinating lecturer: DANIEL DI CAPUA - JOSE JAVIER MUÑOZ ROMERO

Others:

PRIOR SKILLS

Matlab programming.
Application of basic numerical methods for interpolation and integration.
Essentials of partial differential equations

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CEMUEII-03. Use the adequate computational techniques to simulate physical phenomena in engineering. To adapt and apply optimization algorithms in engineering problems.

Generical:
CGMUEII-01. Participate in technological innovation projects in multidisciplinary problems, applying mathematical, analytical, scientific, instrumental, technological and management knowledge.

Transversal:
05 TEQ. TEAMWORK. Being able to work as a team player, either as a member or as a leader. Contributing to projects pragmatically and responsibly, by reaching commitments in accordance to the resources that are available.
06 URI. EFFECTIVE USE OF INFORMATION RESOURCES. Managing the acquisition, structure, analysis and display of information from the own field of specialization. Taking a critical stance with regard to the results obtained.
03 TLG. THIRD LANGUAGE. Learning a third language, preferably English, to a degree of oral and written fluency that fits in with the future needs of the graduates of each course.

TEACHING METHODOLOGY

Theoretical classes with slides and tasks.
Tutorials with modelling software (Matlab) and specific to computer mechanics (Ramseries).
Use of pre- and post-processing software (GiD, ParaView).
In the group work will be allowed to choose the software for the resolution of problems: ABAQUS, ANSYS, Comsol, FEMLAB, GiD, Matlab, ...

LEARNING OBJECTIVES OF THE SUBJECT

1- Be able to indetify a physical problem and the corresponding model for its simulation.
2- Dominate the numerical simulation tools: finite element discretization and optimization program.
3- Identify the boundary conditions and be able to evaluate the accuracy of the solution.
4- Know the basic rheological laws for solids and fluids, and know their respective numerical implementation.
5- Distinguish between linear and non-linear problems, and be able to different type of solution procedures in each case.

STUDY LOAD

Type	Hours	Percentage
Hours large group	27,0	18.00
Self study	96,0	64.00
Hours small group	27,0	18.00

Total learning time: 150 h

CONTENTS

Topic 1: Introduction to Finite Elements

Description:
Analysis of the continuous and discrete problem in one dimension. Numerical integration Reference element. Assembly concept. Extension to two dimensions. Types of elements and implementation. Convergence of the discrete problem. Analysis of flows in the discrete problem, discontinuity and convergence.
Resolution of thermal problems with arbitrary mesh. Pre and post-process. Regularization of the solution by least squares.

Specific objectives:
Strong and weak form of elliptical problems. Concept of discretised problem and origin of errors of the numerical approximation. Physical meaning of the variables.
Differentiate the resolution of nodal variables from the solution of the discretised problem. Evaluate and know how to impose boundary conditions, and know in the derivatives of the discrete problem
Solve the thermal and diffusion problems with arbitrary geometries and contour conditions.
Assembly process in mechanical and electrical systems.

Related activities:
Laboratory session 1.1: Thermal problem 1D-2D
Topics: Computation of system matrix and thermal flow vector. Thermal boundary conditions. Computation of flows and smoothing.

Tasks:
1-) Computation of the thermal system matrix and the flow vector of a triangular element.
2-) Computation of the thermal sytem matrix and the flow vector of a quadrilateral element.
3-) Solution of a small thermal problem

Laboratory session 1.2: Types of finite elements
Topics: Assembly, application of constraints, calculation of variables and flows. Post-processing: use of shape functions in reference elements.
Numerical integration and isoparametric formulation.

Tasks:
1-) Computation of unknowns at the interior of the elements
2-) Numerical integration in an arbitrary quadrilateral element.
3-) Calculation of derivatives of shape functions on distorted quadrilateral element.

Session of the laboratory 1.3: Other discrete problems
Topics: Different types of discrete systems (mechanical, thermal, electrical): Discrete electrical and mechanical problem of bars

Tasks:
1-) Mechanical problem of bars
2-) Discreet electric problem
3-) Numerical resolution

Full-or-part-time: 20h
Theory classes: 4h
Laboratory classes: 4h
Self study : 12h

Topic 2: Elastic solids

Description:
Define the Cauchy equilibrium equations. Deduction of the continuous and discrete weak form. Resolution of problems in two and three dimensions.
Boundary conditions of the elastic problem. Stress analysis

Specific objectives:
Concept of deformation and stress in the continuous and discrete problem.
Resolution of a generic problem. Error analysis.

Related activities:
Laboratory session 2.1: Mechanics of solids
Topics: Calculation of the stiffness matrix and the load vector. Mechanical boundary conditions. Computation of stresses. Smoothed stress analysis and error estimation.

Tasks:
1-) Computation of the stiffness matrix and the load vector of triangular and quadrilateral elements.
2-) Computation of the stiffness matrix and the load vector of tetrahedral and hexahedral elements.
3-) Resolution of a small two-dimensional mechanical problem.

Laboratory session 2.2: Non-linearities
Topics: Geometric non-linearity and material nonlinearity. Numerical resolution: linearisation and Newton-Raphson method.

Tasks:
1-) Non-linear problem with rigidity dependent on the displacements.
2-) Resolution of a geometrically non-linear problem: bars with large displacements.

Full-or-part-time: 16h
Theory classes: 4h
Laboratory classes: 4h
Self study : 8h

Topic 3: Transient problems

Description:
Solution of PDEs and ODEs: Methods of ime discretisation of ODEs: Newmark, centered differences, HHT. Modal analysis. Resonance.

Specific objectives:
Be able to solve parabolic and hyperbolic problems, emphasising the dynamics of the structure.
Identify the solution procedure that best suits the physical problem according to vibration mode, damping (physical and numerical) and required accuracy.

Related activities:
Laboratory session 3.1: Dynamic problems
Topics: Calculation of mass matrix and damping. Direct integration

Tasks:
1-) Calculation of the mass matrix and damping of a triangular element.
2-) Calculation of the mass matrix and damping of a quadrilateral element.
3-) Direct integration of the one-dimensional transient thermal problem. Stability and precision

Laboratory session 3.2: Dynamic problems in solids
Topics: Natural frequencies. Direct integration

Tasks:
1-) Natural frequencies of a dynamic problem
2-) Phenomenon of resonance.

Full-or-part-time: 16h
Theory classes: 4h
Laboratory classes: 4h
Self study : 8h

Topic 4: Fluids

Description:
Main formulations for fluids: Stokes, Navier-Stokes, potential flow. incompressibility,
Formulations of finite elements customary in speeds and pressures.

Specific objectives:
Know how to determine difficulties of fluid problems (LBB condition) and know mixed formulations.

Related activities:
Laboratory session 4.1.: Stationary fluid dynamics
Topics: Flow through porous media (Darcy's problem). Mixed finite elements. Incompressible viscous fluids (Stokes problem).

Tasks:
1-) Calculation of the stiffness matrix of a triangular element for a Darcy problem.
2-) Calculation of the stiffness matrix of a quadrilateral element for a Stokes problem. Stabilisation.

Laboratory session 4.2: Transient fluid dynamics
Topics: Viscous incompressible problems (Navier-Stokes). Interpolation of pressures and velocities. LBB condition.

Tasks:
1-) Solve numerically the Naver-Stokes equations of a two-dimensional domain.
2-) Resolution of non-linear problems with convection. SUPG.

Full-or-part-time: 8h
Theory classes: 2h
Laboratory classes: 2h
Self study : 4h

Topic 5: Optimisation

Description:
Introduction to problem optimization. Applications: transport, mechanics, flow problems, finance.Lagrange multipliers. Interior point methods.
Design of objective functions. Gradient based methods. Basin hopping. Genetic algorithms.
Combination problems. Analysis and modelling of restrictions.

Specific objectives:
Be able to write an optimisation problem in standard form. Identify the space of feasible solutions, objetive functions, and the restrictions.
Choose the most appropriate optimisation method for a given problem and know how to apply and adjust the method to a specific problem.

Related activities:
Laboratory session 5.1: numerical methods (Lagrange multipliers, interior point).
Laboratory session 5.2: methods based on gradients. Basin Hopping.
Laboratory session 5.3: solving problems with genetic algorithms. Introduction to DEAP.
Laboratory session 5.4: resolution of combinational problems or with restrictions.

Full-or-part-time: 32h
Theory classes: 8h
Laboratory classes: 8h
Self study : 16h

ACTIVITIES

Seminars

Description:
Contextualisation of numerical modelling in biomechanics, aeronautics and composite materials.
Presentation of other formulations not seen in the theory sessions: Galerkin discontiniu, mesh-less, DEM, phase-field, X-FEM, ...

Specific objectives:
Motivation and applications of numerical simulation.

Material:
Seminars by experts in modelling. Documentation with slides.

Delivery:
Summary of the sessions and brief questionnaire.

Full-or-part-time: 6h
Self study: 4h
Theory classes: 2h

Presentation Course work

Description:
The students perform the course work in groups, where the concepts developed during the course are applied.
Students choose between a series of statements, with the possibility that they make suggestions of problems with similar difficulty.
Practical applications of the concepts are searched with software to be chosen by each group.
Laboratory hours is a session reserved in the classroom for group work. The hours of theory correspond to the oral presentation of the work.

Specific objectives:
Know how to model an engineering problem, be it fluid or solid. Be able to synthesize and present orally the basic ideas of the work, hypothesis and results of numerical modeling.

Material:
Free or commercial numerical modeling software (ANSYS, COMSOL, Abaqus, FemLab, ..) ..

Delivery:
A document of limited length will be delivered and a public oral presentation of the work will be made.

Full-or-part-time: 28h
Self study: 24h
Theory classes: 2h
Laboratory classes: 2h

GRADING SYSTEM

35% Theory exam.
17.5% Practical assignments (simulation)
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30% Group course project.

This subject will not allow to pass a reassessment test. The criteria that regulate this absence are given in point 1.1.3 of the regulations "Normativa d'Avaluació i Permanència en els estudis de grau i màster de l'EEBE" (https://eebe.upc.edu/ca/estudis/normatives-academiques/documents/normativa-davaluacio-i-permanencia-curs-2024-2025.pdf)

EXAMINATION RULES.

The theory exams are individual. In the evaluations of the laboratory sessions students can share information and access the course documentation.
The course group project will be carried out in groups, and orally presented, together with the written report.

BIBLIOGRAPHY

Basic:
- Hughes, Thomas J. R. The Finite element method : linear static and dynamic finite element analysis. Mineola, New York: Dover Publications, 1987. ISBN 0486411818.
- Zienkiewicz, O. C.; Taylor, Richard Lawrence; Zhu, J. Z. The finite element method : its basis and fundamentals [on line]. 7th ed. Amsterdam [etc.]: Elsevier Butterworth-Heinemann, 2013 [Consultation: 24/04/2020]. Available on: https://www.sciencedirect.com/science/book/9780750664318. ISBN 9781856176330.
- Oñate, E.. Structural analysis with the finite element method : linear statics. Vol. 1: Basis and solids [on line]. Dordrecht: Springer Netherlands, 2009 [Consultation: 24/04/2020]. Available on: http://dx.doi.org/10.1007/978-1-4020-8733-2. ISBN 9781402087332.
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- Eiben, Agoston E.; Smith J. E. Introduction to evolutionary computing. 2nd. Berlin [etc.]: Springer, cop. 2015. ISBN 3662448734.

Complementary:
- Bonet, Javier; Wood, Richard D. Nonlinear continuum mechanics for finite elements analysis. 2nd ed. Cabridge: Cambridge University Press, 2008. ISBN 9780521838702.
- Donea, Jean; Huerta, Antonio. Finite element method for flow problems. Chichester: Wiley, cop. 2003. ISBN 0471496669.
- Malvern, Lawrence E. Introduction to the mechanics of a continuous medium. Englewood Cliffs, NJ: Prentice-Hall, cop. 1969. ISBN 0134876032.
- Holzapfel, Gerhard A. Nonlinear solid mechanics : a continuum approach for engineering. Chichester: John Wiley & Sons, cop. 2000. ISBN 0471823198.
- Kling, Ronn. Learning DEAP from examples. Amazon Media, 2017.