GHENT UNIVERSITY

Course Specifications

Valid as from the academic year 2025-2026

Numerical Modelling and Design of Electrical and Mechanical Systems (E048400)

Course size *(nominal values; actual values may depend on programme)*

Credits 6.0 **Study time 180 h**

Course offerings in academic year 2026-2027

A (semester 1)	English	Gent
B (semester 1)	Dutch	Gent

Lecturers in academic year 2026-2027

Crevecoeur, Guillaume	TW08	lecturer-in-charge
Abdel Wahab, Magd	TW08	co-lecturer
Degroote, Joris	TW08	co-lecturer
Vandevelde, Lieven	TW08	co-lecturer
Verleysen, Patricia	TW08	co-lecturer

Offered in the following programmes in 2026-2027	crdts	offering
Bridging Programme Master of Science in Mechanical and Electrical Systems Engineering	6	A
European Master of Science in Nuclear Fusion and Engineering Physics	6	A
Master of Science in Electromechanical Engineering	6	B
Master of Science in Mechanical and Electrical Systems Engineering	6	A

Teaching languages

English, Dutch

Keywords

Model-based analysis, Design optimization, System development life cycle, Design for eXcellence, Computational Fluid Mechanics, Finite elements methods, Finite volume methods, Numerical techniques, Uncertainty, System identification, Optimal control

Position of the course

This course provides the theoretical and computer-applied basics for the integrated analysis and design of mechanical, electrical, thermo-fluid and control systems. This is realized on the one hand by introducing different numerical optimization techniques that can be deployed to enhance the capabilities of the mechanical, electrical, thermo-fluid and control system and by going further in depth in the different numerical modelling techniques for mechanical, electrical, thermo-fluid and control systems.
The course lies at the crossroad of the four core tracks that constitute the educational program, namely thermo-fluid, mechanical, control and electrical. By means of a model-based analysis and the design for sustainability, the subject also contributes to the numerical techniques and sustainability tracks.
This course is a preparation for the design project in the following semester, and thus a crucial element in the project track of the program.

- Thermo-fluid systems modelling: A fundamental introduction to the computational techniques in fluid mechanics for engineering students.
- Electro-magnetic systems modelling: A fundamental introduction in different simulation techniques of electrical and electromagnetic devices (inter alia the Finite Element Method)
- Structural systems modelling: The course aims at applying the finite element method to mechanical structures. Next to this, students are familiarized with the finite element method for elastic calculations. The possibilities and limitations of

finite element programs are discussed.
- Control systems modelling: An introduction to system identification and optimal control of real-world systems for engineering students.

Contents

The course is organized in two parallel tracks; one deals with design methods and optimization, and one deals with numerical modeling. The content of the different parts is summarized below

- Design: this part introduces the full systems design and optimization workflow for electro-mechanical and control systems. Lectures 1, 10–12 cover the Systems Development Life Cycle (SDLC), detailing phases such as planning, design, and maintenance, with scheduling approaches like waterfall and agile, and design paradigms focusing on sustainability, reliability, manufacturability, and cost-efficiency. Lectures 2–3 lay the foundation of optimization, covering key concepts, problem types (e.g., linear, trajectory, topology), and optimality conditions such as KKT. Lectures 4–5 focus on gradient-based methods for unconstrained and constrained optimization, discussing algorithms like Newton's method and SQP, and techniques for gradient computation. Lectures 6–7 explore stochastic optimization, from simulated annealing to population-based methods such as evolutionary algorithms and CMA-ES, including constraint handling. Finally, Lectures 8–9 introduce advanced topics like surrogate-assisted optimization (e.g., Bayesian), multi-objective optimization (Pareto fronts), optimization under uncertainty (robustness and reliability), and integer programming.
- Thermo-fluid systems modelling: This course provides a comprehensive introduction to computational fluid dynamics (CFD), focusing on both theory and practical application. It begins with the mathematical character of convection-diffusion equations and continues with finite volume methods for steady-state and unsteady flows, including various discretization techniques such as central, upwind, and TVD schemes. Time integration approaches (implicit and explicit) and their stability are addressed. The course covers turbulence modeling, from Reynolds averaging and eddy viscosity models to advanced approaches like RSM, LES, DNS, and transition models. Grid generation is also discussed, including structured and unstructured meshes and different finite volume formulations. Numerical solution strategies are presented, including direct and iterative solvers, multigrid methods, and pressure-velocity coupling techniques. Hands-on exercises with a commercial CFD package include simulations of flow mixing in a tube, discretization scheme comparison in a cavity, wake oscillation behind a cylinder, and evaluation of turbulence models in a dump diffuser setup.
- Electro-magnetic systems modelling: The course spans twelve weeks, combining theory, exercises, and project work in electromagnetic and power system modeling. In Weeks 1–2, students are introduced to Magnetic Equivalent Circuits (MEC) and the Finite Element Method (FEM), including time and frequency domain analysis, nonlinear materials, and coupling with electrical and mechanical systems. Exercises illustrate key phenomena like skin and proximity effects. Weeks 3–6 focus on in-depth FEM theory and application. In Weeks 7–8, attention shifts to modeling and simulation of switching devices in power electronics, with an emphasis on stiff systems. Weeks 9–10 cover nonlinear systems, including load-flow analysis in power grids. Weeks 11–12 culminate in a project integrating an electric grid, power converter, rotating machine, and mechanical load/drive system, applying the concepts developed throughout the course.
- Structural systems modelling: The course aims at applying the finite element method to mechanical structures. Next to this, students are familiarized with the finite element method for elastic calculations. The possibilities and limitations of finite element programs are discussed.
- Control systems modelling: The course introduces system identification and optimal control, focusing on both theory and practical application. It begins with explaining the reality gap that models face with real-world robotic, mechatronic, energy systems; and how to close that gap with computational tools. We elaborate upon uncertainty propagation techniques, Hidden Markov Models and uncertainty quantification techniques. Furthermore, numerical tools are provided for system identification starting from model structures and data, both in the

frequency and time domain. After identifying real-world systems' behavior, we delve into optimal control problem solvers. We specifically investigate trajectory optimization techniques and feedback control design methods. This to design the dynamic behavior of robotic, mechatronic and robotic systems. We close this course with computational tools for non-linear state estimation and adaptive controllers. The latter provides a start towards intelligent controllers that can improve performance, energy efficiency, quality of processes through learning.

Initial competences

- Systems design: Introduction to Numerical Mathematics.
- Thermo-fluid systems modelling: Transport phenomena, Heat and flow engineering
- Electro-magnetic systems modelling: Electromagnetic Energy Conversion, Electrical Machines, Electronics and Power Electronic Power Supplies
- Structural systems modelling: Mechanics of materials and structures, variational principles
- Control systems modelling: Modelling and Simulation of Dynamical Systems, Modelling and Regulating of Dynamical Systems

Final competences

1. Systems design: Overview of system development architectures, design methods and design paradigms (th.), Hands on experience with model-based analysis of mechanical, electrical, thermo-fluid and control systems (detailed in other documents), Mathematical reformulation of the mechanical, electrical, thermo-fluid and control design problem (th.), Overview of optimization techniques (th.), Hands on experience with design optimization techniques (ex.), Critical assessment of system optimality (project)
2. Thermo-fluid systems modelling: Describe selected techniques in computational fluid dynamics, Select appropriate numerical techniques and settings for a flow problem
3. Electro-magnetic systems modelling: to have insights in different simulation techniques of electrical and electromagnetic devices (inter alia the Finite Element Method)
4. Structural systems modelling: To be familiar with the basic notions of the Finite Element Method. To be able to use a commercial finite element package (ANSYS).
5. Control systems modelling: To be familiar with the basic notions of computational tools for system identification and optimal control.

Conditions for credit contract

Access to this course unit via a credit contract is determined after successful competences assessment

Conditions for exam contract

This course unit cannot be taken via an exam contract

Teaching methods

Seminar, Lecture, Independent work

Extra information on the teaching methods

- The theory is taught in lectures.
- Exercises are made by the students, guided by a teaching assistant.
- Project on design and modeling.

Study material

Type: Syllabus

Name: Syllabus (Engels)
Indicative price: Free or paid by faculty
Optional: no

Type: Slides

Name: Slides
Indicative price: Free or paid by faculty
Optional: no

References

- Design for eXcellence, Technicraft Publishers
- Engineering Design, McGraw-Hill

- Numerical Optimization, Springer
- Convex Optimization, Cambridge University Press
- Essentials of Metaheuristics, Lulu Press
- Engineering Design via Surrogate Modelling, Wiley
- An Introduction to Computational Fluid Dynamics: The Finite Volume Method, H. Versteeg and W. Malalasekra,
- Probabilistic robotics, The MIT Press

Course content-related study coaching

- Interactive support through the electronic learning platform (forums, e-mail), in person: after agreement on date, fixed contact hour: immediately before and after lectures.
- Additional guidance by assistant for exercise classes.

Assessment moments

end-of-term and continuous assessment

Examination methods in case of periodic assessment during the first examination period

Written assessment

Examination methods in case of periodic assessment during the second examination period

Written assessment

Examination methods in case of permanent assessment

Assignment

Possibilities of retake in case of permanent assessment

examination during the second examination period is possible in modified form

Extra information on the examination methods

- During Periodic (end-of-term) evaluation: written examination with closed book.
- Second evaluation: written examination with closed book.
- Permanent evaluation: assessment of project report. Frequency: 1 repor

Calculation of the examination mark

Weighting to determine final score: theory exam 50% and project 50%