Bauhaus-Universität Weimar

Module Catalogue
M. Sc. Digital Engineering

Date: January 16, 2023

Contents

I. Curriculum

The Master's degree course in Digital Engineering lasts 4 semesters and comprises 120 credit points (ECTS).

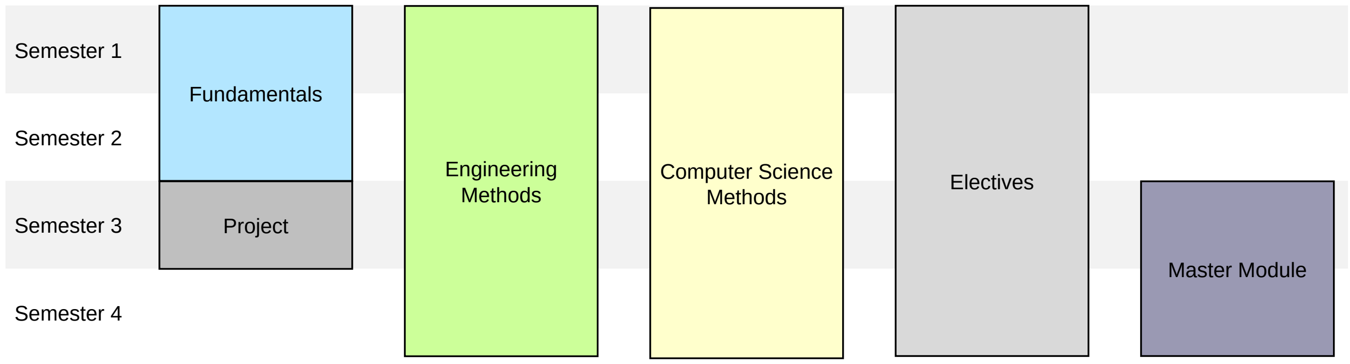
The Compulsory Elective Modules are assigned to three different subject areas, which deal with the following aspects of Digital Engineering: "Fundamentals", "Engineering Methods" and "Computer Science Methods". From each subject area the students choose and complete modules with a total of 18, 36, or 18 ECTS, respectively.

As part of the program admission, three modules from the subject area "Fundamentals" will be assigned individually based on the student's previous knowledge. For the elective modules, students are free to attend Master modules offered at the University, and language courses, thus acquiring additional knowledge and skills.

The project not only aims to expand relevant specialist skills, but also covers interdisciplinary content. Beyond that, it serves as a means of developing further key competences such as teamwork, project management and presentational skills.

Preparation for the final thesis begins as early as the third semester with an initial research phase. This is followed by a period of sixteen weeks during which students produce the thesis itself. The final stage of the Master module is the defense of the thesis.

Name	*ECTS*
Fundamentals (F)	18
Engineering Methods (EM)	36
Computer Science Methods (CSM)	18
Elective Modules	12
Project	12
Master Module	24
Total	120



II. Fundamentals

In the fundamental courses, students learn to recognize and understand engineering-related problems as well as their formulation and implementation using mathematical methods. They acquire abilities to implement mathematical descriptions and develop their own software using modern algorithms and data structures.

Module Title	Module Coord.	ECTS/SWS	Sem.
Algorithms and Data Structures	C. A. Wüthrich	6 ECTS / 4 SWS	SS
Applied Mathematics and Stochastics	B. Rüffer	6 ECTS / 6 SWS	WS
Introduction to Mechanics	T. Rabczuk	6 ECTS / 4 SWS	WS
Mathematics for data science	B. Rüffer	6 ECTS / 4 SWS	WS
Object-oriented Modeling and Programming in Engineering	C. Koch	6 ECTS / 4 SWS	WS
Software Engineering	J. O. Ringert	6 ECTS / 4 SWS	SS
Statistics	B. Rüffer	6 ECTS / 4 SWS	SS

Title	Algorithms and Data Structures	
Semester (optional)	1	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Wüthrich, Charles A. - Chair of Computer Graphics	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the de-gree programme M.Sc. Digital Engineering Compulsory elective module for the degree programme B.Sc. Medienin-formatik Elective module for the degree programme B.F.A. Medienkunst/Medieng-estaltung Elective module for the degree programme M.F.A. Medienkunst/Medieng-estaltung	
Formal requirements for participation		
Recommended requirements for participation		
Required examination (including partial exams if applicable)	Type	written test
	Requirements for exam registration	Pass the implementation exercises
	Language	English
	Duration / Scope	2 hours
	Weighting	

Target qualification	Successful participants master the following concepts and are able to ex-plain them to others: Fundamentals Methods for the organisation of data. Analysis and classification of the complexity of an Algorithm (best case-av-erage case-worst case) Search algorithms, sorting algorithms, algorithms on graphs, flux in net-works. Divide and conquer, space partition algorithms. Geometric algorithms: convex hull, closest points problem. Random numbers, Multiplication of high order Polynomi-als, Fourier trans-forms, Linear and higher order regression, spline based approximation NP-hard problems: Hamilton cycles, Traveling Salesman Problem, undecidi-bility of formal logic, Halt problem of a Turing machine. Successful candidates are able to apply their knowledge and master the fol-lowing: The choice of the correct Data Structure in a programming implementation. The assessment of the complexity of an algorithm. The choice of the appropriate algorithm and its implemen-tation for solving different problems The development and implementation of new algorithms.
Content	The lecture deals with the principle and the implementation of basic algo-rithms and data structures. The course teaches among all, the Strings, geo-metric problems, graphs, math-ematical algorithms and NP-complete prob-lems. - Basic Data Structures, Complexity Analysis, Sorting Algo-rithms. - Hashing and searching - Algorithms on graphs - Geometric algorithms - Divide and Conquer algorithms. - Mathematical algorithms, multiplication of polynomials. - Minumum squares, Fourier transforms. - P- and NP-Problems
Teaching and learn-ing forms/ Didactic concept	Lecture and Exercitations. Implementation of various algo-rithms in the Ex-ercitation. Written final Exam.
Literature and spe-cial information	R. Sedgewick, „Algorithmen“ M. Goodrich and R. Tamassia ‚Algorithm Design”
Courses with SWS / ECTS	This module is comprised of: “Algorithms and Data Structures” (Lecture, 2 SWS) “Algorithms and Data Structures” (Exercises, 2 SWS)

Title	Applied Mathematics and Stochastics	
Semester (optional)	1	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 6 SWS	
Workload	In-class study / online-study	68
	Self-study	82
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. rer. nat. Björn Rüffer – Chair of applied Mathematics Prof. Dr. rer. nat. Tom Lahmer - Chair of Optimization and Stochastics	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in the subject area “Fundamentals” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation		
Required examination (including partial exams if applicable)	Type	Written test
	Requirements for exam registration	
	Language	English
	Duration / Scope	2 hours
	Weighting	

Target qualification	Students will be prepared for mathematical requirements in Computer Aided Engineering (CAE), Signal Processing and Engineering lectures. Introduction to Computer Science based on Computer Algebra Systems for analysis and equation solving. Provision of basic concepts in probability theory and statistics for the assessment of risks of both single components and complex systems. Emphasis on the theory and application of extreme-value distributions. Group-based work enables the students to train their capabilities in team work.
Content	Applied mathematics: Fundamentals of linear algebra, eigenvalue problems, fixed point principles, solvers; Fourier series, convergence, Fourier transform, Laplace transform; Solution of initial value problems, boundary value problems and eigenvalue problems for ordinary differential equations. All topics are discussed from the mathematical point of view and their numerical implementation will be studied. Stochastics: Introduction to probability theory with focus on situations characterized by low probabilities. Random events, discrete and continuous random variables and asso-ciated distributions. Descriptive statistics, parameter estimation. Risk Assessment by means of FORM and Monte Carlo Simulations. Introduction to reliability theory: Extreme value distributions; stochastic modeling with software tools. Reliability Analysis of Systems. Catastrophic events and risk problems, Applications
Teaching and learning forms/ Didactic concept	Lectures and practical sessions combined with individual and group-based studies related to theoretical and practical aspects of the course contents. Practical sessions can include project-oriented and laboratory work based on concrete problems. Theoretical aspects can include reading, understanding and presenting recent pub-lications. Classes consist of one 90-minute lecture and one 90-minute practical ses-sion per week during the semester. Postdoctoral researchers, doctoral students and teaching assistants supervise students and are available for intensive discussion and feedback.
Literature and special information	Montgomery, Runger: Applied Statistics and Probability for Engineers, 2014 / Taan, Karim: Continuous signals and systems with MATLAB, 2008 / Mallat, S.: A wavelet tour of signal processing, 2009
Courses with SWS / ECTS	This module is comprised of: “Applied Mathematics” (Lecture, 2 SWS, Rüffer) “Stochastics” (Lecture, 2 SWS, Lahmer) “Applied Mathematics and Stochastics” (Exercises ,2 SWS, Rüffer/Lahmer)

Title	Introduction to Mechanics	
Semester (optional)	1 or 3	
Frequency	Once a year in the winter semester, at least 5 participants	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Timon Rabczuk – Chair of Computational Mechanics	
Usability / Type of module	Compulsory elective module in subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering Compulsory elective module for the degree programme M.Sc. Bauingenieurwesen Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering	
Formal requirements for participation	Mechanics at Bachelor Level	
Recommended requirements for participation	Basic knowledge of Tensoralgebra and Continuum mechanics	
Required examination (including partial exams if applicable)	Type	Written or oral test depending on number of participants
	Requirements for exam registration	
	Language	English (SuSe), German (WiSe)
	Duration / Scope	150 min. (written) or 30 min. (oral)
	Weighting	
Target qualification	Students can describe the kinematics and kinetics of continua. They know about the balance equations and are able to use different constitutive models. Furthermore the students know about the initial boundary value problem and its applications.	

Content	Main focuses: Introduction to nonlinear continuum mechanics. Kinematics of continua, including Lagrangian and Eulerian description of motion. Deformation gradient and different strain and stress measures. Balance equations for continua, including balance of mass, moment and momentum and energy. Constitutive models for elastic, plastic and viscos material. Creep and rheological model. Initial boundary value problem and application
Teaching and learning forms/ Didactic concept	The topics will be presented in a lecture, deepened in accompanying seminars.
Literature and special information	T. Belytschko, W.K. Liu and B. Moran: Nonlinear Finite Elements for Continua and Structures, Springer, 2001 G.A. Holzapfel: Nonlinear solid mechanics, Wiley, 2006
Courses with SWS / ECTS	This module is comprised of: “Non-linear Continuum Mechanics” (Lecture, 2 SWS) “Non-linear Continuum Mechanics” (Seminar, 2 SWS)

Title	Mathematics for data science	
Semester (optional)	1	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	60
	Self-study	90
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. rer. nat. Björn Rüffer – Chair of applied Mathematics Dr. rer. nat. habil. Michael Schönlein	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in the subject area “Fundamentals" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Analysis and Linear Algebra at Bachelor level	
Recommended requirements for participation	Participants should be familiar with Matlab or Python	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	
	Language	English
	Duration / Scope	2 hours
	Weighting	

Target qualification	After the course the students will be familiar with the fundamental concepts of data science. The participants can analyze given data sets with respect to dimensionality reduction and clustering. They also know the basic structure of neural networks and support vector machines to solve classification tasks. The participants know relevant methods from linear algebra and optimization and can apply these techniques. This embraces the design of appropriate algorithms and the implemention of different numerical methods to solve the corresponding problems.
Content	Singuar value decomposition, generalized eigenvalue problems, Max-min theorem, convex optimization, KKT conditions, strong duality, kernel methods, reproducing kernel Hilbert spaces, Linear Discriminat Analysis, Principle Component Analysis, Regression, Classification, K-means Clustering, Neural networks, deep networks, training deep neural networks, backpropagation
Teaching and learning forms/ Didactic concept	The topics will be presented in a lecture, deepened by exercises.
Literature and special information	R.A. Horn, C. R. Johnson Matrix Analysis, Cambridge Univ. Press 2013 D.A Simovici. Mathematical Analysis For Machine Learning And Data Mining-World Scientific, 2018. M.P. Deisenroth, A. A. Faisal, C. S. Ong, Mathematics for Machine Learning. Cambridge University Press 2021. D.A Simovici. Linear Algebra Tools for Data Mining. World Scientific, 2013. C.C. Aggarwal. Neural networks and deep learning: a textbook. Springer 2018.
Courses with SWS / ECTS	(integrated) Lecture, 4 SWS

Title	Object-oriented Modeling and Programming in Engineering	
Semester (optional)	1	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Christian Koch - Chair of Intelligent Technical Design	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering; Elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering	
Formal requirements for participation		
Recommended requirements for participation		
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	Pass the implementation course-work.
	Language	English
	Duration / Scope	2 hours
	Weighting	
Target qualification	This module covers the basic knowledge needed to develop and implement object-oriented software solutions for engineering problems. This includes the ability to analyse an engineering problem, so that corresponding object-oriented models can be created and suitable algorithms can be selected. The programming language used in this module is Java. However, the since fundamental concepts are described in general, students will be able to program in other modern programming languages.	

Content	Essential programming constructs (alternatives, loops, sequences), Fundamental data structures and algorithms, Principles of object oriented software development (encapsulation, inheritance and polymorphism), The Unified Modeling Language as a tool for software design and documentation, Development of graphical user in-terfaces using the Model-View-Controller pattern.
Teaching and learning forms/ Didactic concept	Interactive lectures with discussions. Implementation of various concepts and algo-rithms taught in the lecture. Coursework task as assignments.
Literature and special information	Meyer, Bertrand Meyer, Touch of class: learning to program well with objects and contracts, Springer, 2013 David J. Barnes, Object-oriented Programming with Java: An Introduction, Prentice Hall, 2000 David Flanagan, Java in a nutshell: a desktop quick reference for java programmers, O’Reilly, 2005
Courses with SWS / ECTS	This module is comprised of: “Object-oriented Modeling and Programming in Engineering” (Lectures, 2 SWS) “Object-oriented Modeling and Programming in Engineering” (Exercises, 2 SWS)

Title	Software Engineering	
Semester (optional)	2	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Jan Oliver Ringert - Software Engineering	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering Compulsory module for the degree programme B.Sc. Medieninformatik	
Formal requirements for participation		
Recommended requirements for participation		
Required examination (including partial exams if applicable)	Type	Written exam or oral exam
	Requirements for exam registration	Successful participation and submission of the exercises.
	Language	English
	Duration / Scope	90 - 105 min
	Weighting	
Target qualification	The students should master the fundamental concepts of developing and maintaining software systems. Especially, they should understand the concepts of divide&concquer, simplicity, rigor and formalization as well as abstraction, information hiding, and hierarchy in software design, implementation, and organization. Students should be able to intensify the theoretical knowledge in practical exercises, in which they will use methods, such as diverse design patterns, architectural patterns, Snow Cards, etc.	

Content	The lecture covers the fundamental principles and techniques in software engineering: Project management (classic and agile) Requirements engineering Responsibility-Driven Design UML Design Patterns Architectures Implementation metrics (e.g., cohesion and coupling) Testing (black-box, white-box, unit tests) Software quality management, refactoring, maintenance, and metrics Software process models
Teaching and learning forms/ Didactic concept	Interactive lectures with discussions and practical work. Exercises will practice the concepts taught concepts so that theory and practice come hand in hand. As teaching concepts, we will use audience response system, buzz groups, randomized team competitions, and others.
Literature and special information	Ian Sommerville: Software Engineering, 8., aktualisierte Auflage, Pearson Studium, 2007 Ghezzi, Jazayeri, Mandrioli: Fundamentals of Software Engineering. 2. Aufl., Pear-son Education, 2002 Gamma, Helm et.al: Design Patterns. Addison-Wesley, 1995
Courses with SWS / ECTS	This module is comprised of: “Software Engineering” (Lectures, 2 SWS) “Software Engineering” (Exercises, 1 SWS

Title	Statistics	
Semester (optional)	2	
Frequency	Once a year in the summer semester, at least 5 participants	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	60
	Self-study	90
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. rer. nat. Björn Rüffer – Chair of applied Mathematics	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in the subject area “Fundamentals” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Module: Applied Mathematics and Stochastics Basic knowledge on random variables and the most important distributions	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	
	Language	English
	Duration / Scope	180 minutes
	Weighting	

Target qualification	Students are taught in basic concepts and methods of statistics and stochastics. Af-ter a successful attendance of the course, the students are able to formulate and analyze concrete problems in terms of mathematics, to grasp the essential characteristics (abstraction) and to develop different approaches using standard methods of stochastics and statistics. They are also able to select a suitable one under differ-ent problem-solving approaches or algorithms and to explain this choice in a com-prehensible manner. Last but not least, the module is intended to contribute to the promotion of objective and secure thinking, as well as to judgment and self-control.
Content	Probability (Events, classical probability, axiomatic approach, conditional probability) Random variables (Discrete random variables, continuous random variables, limit theorems), Descriptive statistics (Graphical representation and frequency distributions, location and scattering parameters, bivariate and multivariate analysis: dependence and correlation, regression analysis), Inductive statistics, Point and interval estimation, Parameter testing, Goodness-of-fit-tests, Nonparametric tests, Tests for independence and correlation.
Teaching and learning forms/ Didactic concept	The topics will be presented in a lecture. They are deepened by exercises, which are to be prepared by the students independently. At a later date, the solutions will be discussed in a joint session.
Literature and special information	Montgomery/Runger: Applied Statistics and Probability for Engineers
Courses with SWS / ECTS	“Statistics” (Lecture, 4 SWS)

III. Engineering Methods

In the subject area ’Engineering Methods’, methods for modeling and simulation are taught. Key objectives are the spatial, temporal and financial modeling, digital model representation and cooperative working by utilizing standard software. Furthermore, choices for the mathematical description and solution of physical models and processes are presented, such as stochastic input and output data as well as non-linear behavior. In this context, techniques for verification, validation, optimizing and identifying input and output data are shown.

Module Title	**Module Coord.**	**ECTS/SWS**	**Sem.**
Advanced Building Information Modeling	C. Koch	6 ECTS / 4 SWS	SS
Complex dynamics	B. Rüffer	6 ECTS / 4 SWS	SS
Computer models for physical processes – from observation to simulation	C. Könke	6 ECTS / 4 SWS	WS
Design and Interpretation of Experiments	T. Lahmer / M. Kraus	6 ECTS / 6 SWS	WS
Experimental Structural Dynamics	V. Zabel	6 ECTS / 4 SWS	SS
Finite Element Methods	C. Könke	6 ECTS / 6 SWS	WS
Indoor Environmental Modeling	C. Voelker / H. Alsaad	6 ECTS / 4 SWS	SS
Introduction to Mobility and Transport	U. Plank-Wiedenbeck	6 ECTS / 4 SWS	WS
Macroscopic Transport Modeling	U. Plank-Wiedenbeck	6 ECTS / 4 SWS	SS
Microscopic Traffic Simulation	U. Plank-Wiedenbeck	6 ECTS / 4 SWS	SS
Modelling of Steel Structures and Numerical Simulation	M. Kraus	6 ECTS / 4 SWS	SS
Optimization	T. Lahmer	6 ECTS / 6 SWS	SS
Simulation Methods in Engineering	C. Koch	6 ECTS / 4 SWS	SS
Spatial Information Systems (GIS)	V. Rodehorst	6 ECTS / 4 SWS	WS
Stochastic Simulation Techniques and Structural Reliability	T. Lahmer	6 ECTS / 4 SWS	SS
Structural Dynamics	V. Zabel	6 ECTS / 6 SWS	WS

Title	Advanced Building Information Modeling	
Semester (optional)		
Frequency	Once a year in the summer semester, at least 5 participants	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Christian Koch - Chair of Intelligent Technical Design	
Usability / Type of module	Compulsory elective module in the subject area "Modelling" for the degree programme M.Sc. Digital Engineering; Elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge of Computer-Aided Design, BIM concepts, and object-oriented programming	
Required examination (including partial exams if applicable)	Type	written report, presentation
	Requirements for exam registration	1 early presentation on selected research topic outlining the plan of work,
	Language	English
	Duration / Scope	20-40 pages report
	Weighting	report 70%, presentation 30%

Target qualification	This module introduces advanced concepts of Building Information Modelling (BIM) to provide students with advanced knowledge in order to understand, analyze and discuss scientific research approaches related to BIM. Within the frame of the module project (coursework) the students will choose a topic from a pre-defined list or come up with their own topic. Based on that they will do detailed research, implement a representative concept in a software prototype and discuss findings and limitations. Also, the students acquire skills of scientific working and presentation.
Content	Advanced geometric and parametric modelling, Interoperability and collaboration concepts (IFC, IDM, BEP), Advanced use cases (e.g. clash detection, as-built mod-eling), BIM programming (incl. visual programming)
Teaching and learning forms/ Didactic concept	Lectures, including guest lectures from academics; Seminars and hands-on tutorials in computer pool; Student presentations and peer assessment. The lectures provide the theoretical background that is exemplary applied in computer exercises and individual projects.
Literature and special information	Eastman, C., Teichholz, P., Sacks, R., Liston, K. (2011), BIM Handbook: A guide to Building Information Modelling, 2nd edition, Wiley. Borrmann, A., König, M., Koch, C., Beetz, J. (2018), Building Information Model-ing: Technological Foundations and Industry Practice, Springer Vieweg. Mortenson, M.E. (2006), Geometric Modeling, 3rd edition, Instustrial Press. Shah, J.J., Mäntylä, M. (1995), Parametric and feature-based CAD/CAM – Con-cepts, Techniques and Applications. Liebich, T. (2009), IFC 2x Edition 3 Model Implementation Guide, Version 2.0.
Courses with SWS / ECTS	This module is comprised of: “Advanced Building Information Modelling” (Lecture, 2 SWS) “Advanced Building Information Modelling” (Seminar, 2 SWS)

Title	Complex dynamics	
Semester (optional)	2 or 4	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	60
	Self-study	90
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. rer. nat. Björn Rüffer – Chair of applied Mathematics	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in the subject area "Modelling" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Bachelor level mathematics; Participants should be familiar with a programming language such as Matlab or Python	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	
	Language	English
	Duration / Scope	2 hours
	Weighting	

Target qualification	After the course the students will be able to analyse mathematical models that describe dynamic behaviour, as they occur in engineering (e.g. mechanical coupling of building structures), in biology and in physics, but also in multi-agent systems in computer science, or as opinion dynamics in psychology. Based on examples from different disciplines, students learn to build simplified models that allow to answer questions on their long term behaviour. Students will be able to apply methods of feedback design that help shape the dynamics of a given system, along with the relevant stability concepts. As several topics lend themselves for computer simulation, students of this course will develop a proficiency to both implement and analyse mathematical models using computational tools and software.
Content	Examples of complex dynamics. Models for dynamical systems in continuous and discrete time. Computer simulation. Control and Feedback. Stability, stabilization, and Lyapunov functions. Coupled systems: Disturbance or Cooperation? Networks of systems. Consensus. Synchronization.
Teaching and learning forms/ Didactic concept	The topics will be presented in a lecture, deepened by exercises. Some of the exercise include computer programming and simulation.
Literature and special information	Will be announced in the lecture
Courses with SWS / ECTS	This module is comprised of: “Complex dynamics” (integrated Lecture, 4 SWS)

Title	Computer models for physical processes – from observation to simulation	
Semester (optional)	3	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Carsten Könke, Prof. for Structural Analysis and Component Strength	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the degree program M.Sc. Digital Engineering Elective module for M.Sc. Natural Hazards Mitigation in Engineering	
Formal requirements for participation		
Recommended requirements for participation	basic course in structural mechanics basic course in applied mathematics	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	study work and passing the oral defense of the study work at the end of the semester
	Language	English
	Duration / Scope	180 minutes
	Weighting	

Target qualification	Student will be able to formulate a numerical approximate solution for a problem in physics, e.g. heat flow problem or problem from structural mechanics. He will be able to establish the governing equations starting from energy formulations or conservation equations. He will be capable of transferring the strong form of a physical problem description into a weak form and will be able to solve either the partial differential equation system with discretization techniques, such as finite dif-ference methods or finite element methods. He will be capable of assessing the quality of the obtained numerical solution.
Content	Mechanical formulation of physical problem via energy principles or conservation laws. Strong and weak formulation of the physical form. Finite difference solution of ordinary and partial differential equations. Finite element solution of the weak form of a physical problem statement (heat flow problem or structural mechanics). Error estimates for numerical solution techniques, Zienkiewicz/Zhu and Babushka/Rheinboldt approach
Teaching and learning forms/ Didactic concept	Lectures and practical sessions (tutorials) in classroom, Tutorials in computer pools. Assisted project work in the semester finalized with an oral presentation given by students.
Literature and special information	Eriksson, Estep, Hansbo, Johnson, Computational Differential Equations Bathe, K.J., Finite Element Procedures Lecture handouts
Courses with SWS / ECTS	This module is comprised of: “Computer models for physical processes” (Lectures 2 SWS) “Computer models for physical processes” (practical sessions computer lab, 2 SWS) “Computer models for physical processes” (Tutorials, optional)

Title	Design and Interpretation of Experiments	
Semester (optional)	1 or 3	
Frequency	Once in a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 6 SWS	
Workload	In-class study / online-study	56
	Self-study	94
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. rer. nat. Tom Lahmer - Chair of Optimization and Stochastics Prof. Dr.-Ing. Kraus, Matthias – Chair of Steel and Hybrid Structures	
Usability / Type of module	Compulsory module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in the subject area "Simulation and Validation" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Participation in Module „Applied Mathematics and Stochastics"	
Recommended requirements for participation	Good knowledge in Applied Mathematics	
Required examination (including partial exams if applicable)	Type	1 Written exam / 120 min / WiSe + SuSe including „Experiments in Structural Engineering" and „Signal Processing, Design of Experiments and System Identification"
	Requirements for exam registration	Submission of Solutions of Computer Classes
	Language	English
	Duration / Scope	3 hours
	Weighting	Project Report (33 %)
Written exam (67 %)		

Target qualification	Students will be familiar with following: Design and setup as well as evaluation and interpretation of experimental testing in structural engineering. Provision of tech-niques linking experimental and mathematical / numerical modeling. Parallel as-sessment of steps being part of any verification and validation procedure. Discus-sion of common techniques of optimal experimental designs. As submission of results of computer classes can be done in groups, the students learn additionally to work in small groups and improve their social skills while treating demanding engineering and mathematical tasks.
Content	The course gives an overview on experiments and their evaluation regarding differ-ent tasks and scopes of structural engineering. Next to different testing techniques applied for diverse aims, the equipment and measuring devices employed for testing are treated as well. Besides the experiment itself, it is an important question, how we can use the experimental data for the calibration and validation of models in engineering. In this course, we give insights to techniques called parameter and system identification. As often signals are not useable directly, transforms are necessary, like filtering, Fourier Transform, Wavelet Transform and, in particular for signals with noise, averaging techniques. Having models at hand, the experiment can be designed virtually by means of nonlinear optimization
Teaching and learning forms/ Didactic concept	Lectures and practical sessions combined with individual and group-based studies related to theoretical and practical aspects of the course contents. Practical sessions can include project-oriented and laboratory work based on concrete problems. Theoretical aspects can include reading, understanding and presenting recent publications. Classes consist of one 90-minute lecture and one 90-minute practical session per week during the semester. Postdoctoral researchers, doctoral students and teaching assistants supervise students and are available for intensive discussion and feedback.
Literature and special information	Farrar, Worden: Structural Health Monitoring, A Machine Learning Perspective, WILEY Ucinski: Optimal Measurement Methods for Distributed Parameter System Identification
Courses with SWS / ECTS	This module is comprised of: “Signal Processing, Design of Experiments and System Identification” (Lecture, 2 SWS, Lahmer) “Signal Processing, Design of Experiments and System Identification” (Computer Classes, 1 SWS, Lahmer) “Experiments in Structural Engineering” (Lecture, 2 SWS,Kraus)

Title	Experimental Structural Dynamics	
Semester (optional)	2 or 4	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	68
	Self-study	72
	Exam preparation	40
Language of instruction	English	
Module coordinators	Dr.-Ing. habil. Zabel, Volkmar – Chair of Structural Analysis and Component Strength	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module for the degree programme M.Sc. Bauingenieurwesen Compulsory elective module in the subject area "Simulation and Validation" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Structural Dynamics or equivalent	
Recommended requirements for participation	Structural Dynamics, Linear Finite Elements	
Required examination (including partial exams if applicable)	Type	1 Project Report + Presentations / Project Work
	Requirements for exam registration	Intermediate Presentations
	Language	English
	Duration / Scope	
	Weighting	

Target qualification	The students obtain deepened knowledge in structural dynamic analysis, pro-cessing of measured data, numerical implementation of identification methods, dy-namic test equipment and its handling. They obtain experience in creating, validat-ing and updating of numerical models representing the dynamic behaviour of a structure utilizing state-of-the-art methods. Further, the students develop compe-tences required for teamwork such as respective communication and presentation skills as well as experience in international collaboration.
Content	Statespace models, system identification and operational modal analysis, data anal-ysis and assessment, structural modelling, model updating, sensor types, sensor handling
Teaching and learning forms/ Didactic concept	In the first part of the course the theoretical concepts and experimental sample presentations will be given in form of lectures and seminars. As well starting at the beginning of the course but with increasing intensity, the students have to develop strategies and concepts of investigation to solve given problems within a project and implement them. The project work is organized in small groups of students who have to collaborate. Therefore the students will enhance their social compe-tence, especially in the field of team work, presentation techniques, communica-tion, coordination, international and intercultural collaboration.
Literature and special information	Recommended Literature: Van Overschee, P. & De Moor, B.: Subspace identification for linear systems - The-ory, implementation, applications, 1996 Ljung, L.: System identification: theory for the user, 1987 Juang, J.-N.: Applied system identification, 1994 Bendat, J. S. & Piersol, A. G.: Random data: Analysis and measurement procedures, 2010 Ewins, D.J.: Modal Testing: Theory, Practice and Application, 2nd edition, 2000 Maia, N.M.M., Silva, J.M.M. (eds.): Theoretical and Experimental Modal Analysis, 1997 Rainieri, C. & Fabbrocino, G.: Operational Modal Analysis of Civil Engineering Structures, 2014
Courses with SWS / ECTS	This module is comprised of “Experimental Structural Dynamics” (integrated Lectures, 2 SWS) Assisted Lab/Field experiments and partly assisted Project Work (2 SWS).

Title	Finite Element Methods	
Semester (optional)	2 or 4	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 6 SWS	
Workload	In-class study / online-study	40
	Self-study	35
	Exam preparation	15
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Carsten Könke, Prof. for Structural Analysis and Component Strength	
Usability / Type of module	Compulsory elective module in the subject area "Modeling" for the degree program M.Sc. Digital Engineering Elective module for M.Sc. Natural Hazards Mitigation in Engineering	
Formal requirements for participation		
Recommended requirements for participation	basic course in structural mechanics and basic course in applied mathematics	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	1 home work accepted
	Language	English
	Duration / Scope	90 minutes
	Weighting	

Target qualification	Students will obtain the ability to analyse complex structural engineering problems applying numerical simulation techniques, to establish numerical approximation methods for structural engineering problems starting with the PDE and ending in a discretized form of a weak formulation. They will be able to solve systems of partial differential equations by approximate methods using FEM approaches. They will be able to assess the quality of FEM solutions, i.e. numerical discretization errors and specific defects of certain FEM formulations, such as locking phenomena of displacement based elements. They will obtain the ability to analyze nonlinear problems in FEM, e.g. analyse geometrical nonlinear structural engineering problems and to establish numerical models for static and dynamic problems in structural engineering. They will understand differerences between displacement based elements and more sophisticated formulations, such as mixed elements. They will be able to assess the quality of FEM solutions using Z/Z and Babuska/Rheinboldt approaches. They will understand the relevance of eigenvalue problems and how to solve them.
Content	strong and weak form of equilibrium equations in structural mechanics, Ritz and Galerkin principles, shape functions for 1D, 2D, 3D elements, stiffness matrix, numerical integration, Characteristics of stiffness matrices, solution methods for linear equation systems, post-processing and error estimates, defects of displacements based formulation, mixed finite element approaches. Differences between linear and nonlinear problems in engineering. Linearization of nonlinear problems. Finite element formulation for geometrical and physical nonlinear problems in structural engineering, incremental-iterative concepts, quality assessment of numerical results via error estimates, efficient solver techniques for large linear and nonlinear equation systems resulting from the FE concepts, eigenvalue problems in physical processes amd FEM, application of FE-methods for typical engineering problems (50 % of course time)
Teaching and learning forms/ Didactic concept	Lectures and practical sessions (tutorials) in classroom. Practical sessions in computer pool.
Literature and special information	Kassimali, A. Structural Analysis, Cengage Learning, Stanford; Bathe, K.J., Finite Element Procedures Lecture handouts
Courses with SWS / ECTS	This module is comprised of: “Finite Element Methods” (Lectures, 3 SWS) “Applied Finite Element Methods” (Seminars, 3 SWS)

Title	Indoor Environmental Modeling	
Semester (optional)		
Frequency	Once a year in the summer semester, at least 5 participants	
Interval and duration	Weekly for one semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Conrad Voelker - Chair of Building Physics Dr.-Ing. Hayder Alsaad - Chair of Building Physics	
Usability / Type of module	Compulsory elective module in the subject area “Simulation and Validation” for the degree programme M.Sc. Digital Engineering.	
Formal requirements for participation		
Recommended requirements for participation	Basic background in simulations	
Required examination (including partial exams if applicable)	Type	Group report, group presentation
	Requirements for exam registration	
	Language	English
	Duration / Scope	15-20 pages report, presentation
	Weighting	Report 70%, presentation 30%

Target qualification	The module introduces the investigation and assessment of the indoor environment with focus on the simulation and validation aspects of this topic. The students will learn the fundamentals of the indoor environment, the methods of indoor environmental simulations, and the empirical measurements required for the validation of the simulations. This module involves a group project in which the students begin with conducting empirical measurements at the laboratories of the Chair of Building Physics and move on to modeling these experiments, validating their models, and extending their simulations for further assessments. Through these tasks, the students will learn the necessary skills needed for scientific research, advanced simulation tools, scientific writing, presentation, and teamwork.
Content	Fundamentals of thermal comfort Fundamentals of indoor air quality Computational fluid dynamics Empirical measurements Flow visualization Data analysis
Teaching and learning forms/ Didactic concept	Integrated lectures and experimental work in the laboratory
Literature and special information	REHVA. Guidebook No 14 - Indoor climate quality assessment. Brussels, Belgium: The Federation of European Heating, Ventilation and Air Conditioning associations 2011. ASHRAE. 2021 ASHRAE Handbook: Fundamentals. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers 2021. Peyret, Roger. Handbook of Computational Fluid Mechanics. Elsevier Science 1996
Courses with SWS / ECTS	This module is comprised of: “Indoor Environmental Modeling” (Integrated lecture, 4 SWS)

Title	Introduction to Mobility and Transport	
Semester (optional)		
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	50
	Self-study	100
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Uwe Plank-Wiedenbeck – Chair of Transport System Planning	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	approval by chair of transportation system planning B.Sc., International students: individual assessment	
Recommended requirements for participation	prior knowledge: -	
Required examination (including partial exams if applicable)	Type	Exam and project work with presentation
	Requirements for exam registration	project completion
	Language	English
	Duration / Scope	60 minutes
	Weighting	written exam /60min/eng/SoSe+WiSe/(50%)
Project work/eng/SoSe/(50%)		

Target qualification	Introduction of assessment procedures as three phase-models. Deep understanding of the interface between transport modelling (output data) and assessment procedures (necessary input data). Key issues affecting the planning, design, management and financing of public transport. Awareness-raising about the potential of public transport services and offers to achieve safe, environmentally friendly and accessible mobility and traffic solutions. Ability to estimate/ calculate significant parameters in the field of public transportation planning and management. Students will be introduced to data-oriented working methods and should develop an understanding of the future significance of mobility and traffic data. They will learn how to use data science tools and will be enabled to critically discuss data analysis results
Content	Introduction of Transport Planning process: target system, concepts and measures, indicators and aggregation procedures (Benefit Cist Analysis (BCA), Weighted Benefit Analysis (WBA), etc.) as components of assessment procedures. Processing of transport model results (traffic volumes per link etc.) as input for the assessment procedure (concept of time variation curves). Calculation of indicators and deduction of monetary values for indicators (Value of Time etc.). German Federal Transport Infrastructure Plan 2030 (FTIP) and European method for the assessment of measures for walking and cycling (FLOW tool), application by well-guided practical exercises. Application-oriented data science basics, sources and quality of mobility and traffic data, work with data science tools, data analysis with methods of artificial intelligence and machine learning, evaluation and discussion of results
Teaching and learning forms/ Didactic concept	Integrated Lecture (iL)
Literature and special information	PTV GROUP; TCI RÖHLING; MANN: Methodology Manual for the Federal Transport Infrastructure Plan 2030 (2016) | ORTÚZAR; WILLUMSEN: Modelling Transport, 4th Edition (2011) | QUINET; VICKERMAN: Principles of Transport Economics (2005) | VARIAN: Microeconomic Analysis (1992) Further literature references will be announced at the beginning of the semester
Courses with SWS / ECTS	The module comprises of: “Introduction to Transport Systems and Planning” (Lecture, 2 SWS) “Project: Data Science for Mobility and Transport” (Exercise, 2 SWS)

Title	Macroscopic Transport Modeling	
Semester (optional)		
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Uwe Plank-Wiedenbeck – Chair of Transport System Planning	
Usability / Type of module	Compulsory elective module in the subject area “Modeling” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	approval by chair of transportation system planningB.Sc., International students: individual assessment	
Recommended requirements for participation	prior knowledge: modelling/ simulation and/or traffic planning and traffic engineering	
Required examination (including partial exams if applicable)	Type	Exam and project work with presentation
	Requirements for exam registration	project completion
	Language	English
	Duration / Scope	60 minutes
	Weighting	written exam /60min/eng/SoSe+WiSe/(50%)
Project work/eng/SoSe/(50%)		

Target qualification	Understanding and competences for application of macroscopic transport models for analyses and fore castings of passenger transport demand. Knowledge of necessary data for modelling processes as well as acquisition of required information and data processing within the modelling process. Broad understanding of the classical four-step-modelling approach and its various components and related approaches in detail. Development of an integrated multi-modal transport model. User experience with the PTV-software VISUM. Understanding and sense to deal with the model outputs in order to achieve reliable statements.
Content	Part A: Principles Transport planning framework, Methodology and procedures, Land-Use Data and networks, Empirical Travel Data for model developments, Trip generation, Trip distribution, Mode choice, Traffic assignment, Methods and algorithms, Strengths and weaknesses of different model approaches, Calibration and validation, Forecasting and scenario calculations Part B: Model Development Practical implementation and application, Modelling transport network and travel demand using PTV VISUM, Application of learned methodological approach(es) and critical reflection of the model outputs, Student presentation (group work)
Teaching and learning forms/ Didactic concept	Integrated Lecture (IL)
Literature and special information	ORTÚZAR; WILLUMSEN: Modelling Transport, 4th Edition (2011) SCHNABEL; LOHSE: Grundlagen der Straßenverkehrstechnik und Verkehrsplanung, Bd.1: Straßenverkehrstechnik (2011) SCHNABEL; LOHSE: Grundlagen der Straßenverkehrstechnik und Verkehrsplanung, Bd.2: Verkehrsplanung (2011) further literature: CASCETTA: Transportation Systems Analysis – Models and Applications (2009)
Courses with SWS / ECTS	The module comprises of: “Macroscopic Transport Modelling” (Lecture, 2 SWS) “Macroscopic Model Development” (Exercise, 2 SWS)

Title	Microscopic Traffic Simulation	
Semester (optional)		
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Uwe Plank-Wiedenbeck – Chair of Transport System Planning	
Usability / Type of module	Compulsory elective module in the subject area "Modeling" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	approval by chair of transportation system planning B.Sc., International students: individual assessment	
Recommended requirements for participation	prior knowledge: modelling/ simulation and/or traffic planning and traffic engineering	
Required examination (including partial exams if applicable)	Type	Exam and project work with presentation
	Requirements for exam registration	project completion
	Language	English
	Duration / Scope	60 minutes
	Weighting	written exam /60min/eng/SoSe+WHWiSe/(50%) Project work/eng/SoSe/(50%)

Target qualification	Acquire basic knowledge and methods in traffic management and detailed knowledge in microscopic traffic modeling. Acquire detailed knowledge in microscopic transport modeling with modeling procedures. Acquire essential knowledge in data science in transportation with data acquisition and processing. Acquire essential knowledge in model calibration and validation. Acquire basic knowledge in self-adapting traffic models and sensitivity analysis. Related to the following Sustainable Development Goals of the UN: 9, 11
Content	Lecture: Microscopic Traffic Simulation 1.) Fundamentals • Basics and use-cases of traffic management and traffic engineering • Introduction Modeling Approach in Transportation, vehicle-follow-up-model, social-force-model, multimodal interaction • Basics of modeling procedures, probability approach, goals and limitations of computer simulations 2.) Microscopic transport modeling procedures • Vehicle network modeling and simulation options • Microscopic modeling of public transport and passengers • Application of micro simulation, simulation quality and need of calibration and validation 3.) Data Science in Transportation • Acquisition of traffic relevant signals and data • Basics of signal preparation and deployment • Data mining in transport planning and traffic management 4.) Advanced modeling approaches • Basics of parametrization and traffic model calibration • Evaluation approach and traffic model validation • Sensitivity analysis and quality specification • Perspective: Self-adapting traffic models (recursive model calibration) Project Work: Software-based Simulation of Traffic and Emissions • creating an unsignalized intersection from scratch • simulate and evaluate an unsignalized intersection • create, simulate and evaluate an signalized intersection • adapt and simulate an existing model • calibrate and validate an existing model • evaluate a traffic management measure

Teaching and learning forms/ Didactic concept	Integrated Lecture (iL)
Literature and special information	Treiber, M. (2013): Traffic flow dynamics: data, models and simulation Beyer, J. (2015): Cybernetics in planning and operation to assist prospective public transportation systems, International Conference on Modeling the Future of Ho Chi Minh City, Binh Duong New City, Binh Duong Province, Vietnam, September 2015, ISBN: 978-604-913-414-2 PTV AG: PTV Vissim 2022 User Manual CURRENT RULES AND REGULATIONS OF THE GERMAN RESEARCH SOCIETY FOR ROAD AND TRAFFIC ENGINEERING (FGSV): Hin-weise zur Datenvervollständigung und Datenaufbereitung in verkehrstechnischen Anwendungen (Nr. 382); Arbeitspapier – Data Mining im Verkehrsmanagement und in der Verkehrsplanung: Anwendungen und Verfahren (Nr. 382/2); Hinweise zur mikroskopischen Verkehrsflusssimulation – Grundlagen und Anwendung (Nr. 388), e.g. Umweltbundesamt:Handbook Emission Factors for Road Transport – HBEFA (2019) Treiber, M. (2013): Traffic flow dynamics: data, models and simulation Beyer, J. (2015): Cybernetics in planning and operation to assist prospective public transportation systems, International Conference on Modeling the Future of Ho Chi Minh City, Binh Duong New City, Binh Duong Province, Vietnam, September 2015, ISBN: 978-604-913-414-2 PTV AG: PTV Vissim 2022 User Manual CURRENT RULES AND REGULATIONS OF THE GERMAN RESEARCH SOCIETY FOR ROAD AND TRAFFIC ENGINEERING (FGSV): Hin-weise zur Datenvervollständigung und Datenaufbereitung in verkehrstechnischen Anwendungen (Nr. 382); Arbeitspapier – Data Mining im Verkehrsmanagement und in der Verkehrsplanung: Anwendungen und Verfahren (Nr. 382/2); Hinweise zur mikroskopischen Verkehrsflusssimulation – Grundlagen und Anwendung (Nr. 388), e.g. Umweltbundesamt:Handbook Emission Factors for Road Transport – HBEFA (2019)
Courses with SWS / ECTS	The module comprises of: “Microscopic Traffic Simulation” (Lecture, 2 SWS) “Software-based Simulation of Traffic and Emissions” (Exercise, 2 SWS)

Title	Modelling of Steel Structures and Numerical Simulation	
Semester (optional)	2 or 4	
Frequency	Once a year in the summer semester, at least 5 participants	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Kraus, Matthias – Chair of Steel and Hybrid Structures	
Usability / Type of module	Compulsory elective module in the subject area “Simulation and Validation” for the degree programme M.Sc. Digital Engineering Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering	
Formal requirements for participation		
Recommended requirements for participation	Structural Engineering Models, Linear FEM, Nonlinear FEM	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	
	Language	English
	Duration / Scope	120 minutes
	Weighting	
Target qualification	The students will be familiar with skills and expertise in the field of nonlinear structural analyses. Extensive knowledge of theoretical basics and modern modelling methods including numerical representations are the aim of the course. The students will acquire skills in handling advanced tools for the analysis and the design of structures.	

Content	Design of steel structures using finite element methods; basics of the design; mod-elling of structures and loads; nonlinear material behaviour, numerical analyses of steel-members and structures regarding geometric and physical nonlinearities; sta-bility behaviour of members including flexural and lateral torsional buckling
Teaching and learning forms/ Didactic concept	Lectures, exercises in lecture hall, exercises in computer pool, self-study. Lectures provide the theoretical background, which is exemplarily applied to prac-tical tasks in exercises including computer applications
Literature and special information	Literature: Kindmann, R., Kraus, M.: Steel Structures – Design using FEM. Ernst & Sohn pub-lishing, Berlin 2011 Internal lecture notes
Courses with SWS / ECTS	This module is comprised of: “Modelling of steel structures and numerical simulation” (Lecture, 2 SWS) “Modelling of steel structures and numerical simulation” (Exercise, 2 SWS)

Title	Optimization
Semester (optional)	2 or 4
Frequency	Once in a year in the summer semester
Interval and duration	Weekly for 1 semester
ECTS / credit points	6 ECTS / 6 SWS
Workload	In-class study / online-study: 68 Self-study: 82 Exam preparation: 30
Language of instruction	English
Module coordinators	Prof. Dr. rer. nat. Tom Lahmer - Chair of Stochastics and Optimization
Usability / Type of module	Compulsory elective module in the subject area “Modelling” for the degree programme M.Sc. Digital Engineering Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering
Formal requirements for participation	
Recommended requirements for participation	Basic knowledge of calculus and algebra necessary. Programming skills, e.g. Matlab are of help but not necessary.
Required examination (including partial exams if applicable)	Type: Written or oral exam + Project (depending on the number of participants) Requirements for exam registration: Submission and Presentation of results from computer classes Language: English Duration / Scope: 90 minutes (written) or 30 minutes (oral) Weighting: „Introduction to Optimization“/ (50%) / WiSe+ SuSe
„Optimization in Applications“/ (50%) / SuSe + WiSe	

Target qualification	The students will have a fair overview about typical optimization problems. After the course, students can easily detect the potential of improvements in technical, economic or social systems. The students have the ability to formulate optimization problems in mathematical terms on their own and to classify the resulting problem. Depending on this classification, students have good training in finding suitable and efficient optimizers to solve the problems. Students have good insights into main parts of the optimization methods available.
Content	Introduction to Optimization: Linear Problems, Simplex Method, Duality Nonlinear Problems: Constrained and unconstrained continuous problems, descent methods and variants Optimization using Graph Theory Optimization in Applications: This course treats topics concerned with the combination of optimization methods and (numerical) models. Typical problems, where such combinations arise are Cali-bration of Models, Inverse Problems; (Robust) Structural Optimization (including Shape and Topologyoptimization); Design of Experiments
Teaching and learning forms/ Didactic concept	The teaching form consists mainly of lectures enriched by computer classes and self-study. Results of the computer classes need to be presented in front of the class at the end of the semester
Literature and special information	I. M. Bomze, W. Grossmann - Optimierung -Theorie und Algorithmen - Eine Einführung in Operations Research für Wirtschaftsinformatiker C.T. Kelley - Iterative methods for Optimization L. Harzheim – Strukturoptimierung - Grundlagen und Anwendungen
Courses with SWS / ECTS	This module is comprised of: “Introduction to Optimization”, (Lecture, 2 SWS + Computer Class. 1SWS, valid 3 ECTS) “Optimization in Applications”, (Project, valid 3 ECTS)

Title	Simulation Methods in Engineering	
Semester (optional)		
Frequency	Once a year in the summer semester, at least 5 participants	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Christian Koch - Chair of Intelligent Technical Design	
Usability / Type of module	Compulsory elective module in the subject area “Simulation and Validation” for the degree programme M.Sc. Digital Engineering; Compulsory module for the degree programme M.Sc. Umweltingenieurwissenschaften; Elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge of programming	
Required examination (including partial exams if applicable)	Type	group report, group presentation
	Requirements for exam registration	
	Language	English
	Duration / Scope	20-40 pages report, presentation
	Weighting	report 70%, presentation 30%

Target qualification	This module provides students with comprehensive knowledge about computer based simulation concepts to address practical challenges in engineering. Modern simulation and optimization software is introduced within tutorials. The module project (coursework) offers an opportunity to students to work in groups on cur-rent problems in the context of civil and environmental engineering (e.g. production logistics, pedestrian simulation, pollutant dispersion). Using object-oriented simulation software the students will analyze, model and simulate different engi-neering systems. The programming is carried out using Java. Also the students acquire team working and presentation skills.
Content	- System analysis and modelling - System dynamics - Discrete event simulation - Multi-agent simulation - Input data and stochastic simulation - Simulation based optimization - Introduction to the software AnyLogic
Teaching and learning forms/ Didactic concept	Lectures; Seminars/ tutorials in computer pool; group project, student presenta-tions. Lectures provide theoretical foundations that are applied in practical com-puter exercises and a comprehensive student group project.
Literature and special information	Banks, J. (1998), Handbook of Simulation: Principles, Methodology, Advances, Ap-plications, and Practice, Wiley. Banks, J., Carson, J.S., Nelson, B.L. (2009), Discrete-Event System Simulation, 5th edition, Pearson Education. Borshchev, A. (2013), The Big Book of Simulation Modeling: Multimethod Model-ing with Anylogic 6, AnyLogic North America.
Courses with SWS / ECTS	This module is comprised of: “Simulation methods in Engineering” (Lecture, 2 SWS) “Simulation methods in Engineering” (Seminar, 2 SWS)

Title	Spatial Information Systems (GIS)	
Semester (optional)	1 or 3	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Volker Rodehorst - Computer Vision in Engineering	
Usability / Type of module	Compulsory elective module in the subject area “Modeling” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation		
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	Successful completion of the lab classes
	Language	English
	Duration / Scope	90 minutes
	Weighting	examination 100%, successful completion of the project

Target qualification	The students can use the topics below to solve spatially related problems. They are able to formalize and generalize their own solutions by applying the concepts of geo-spatial data acquisition, organization, analysis and presentation. Students will be able to realize the conceptual design and realization of a GIS, the collection of subject-specific geo-spatial data as well as the application for location-based services, geo-marketing and strategic site planning in order to address problems of spatial information systems and their application to digital media. They should be able to understand the proposed concepts, to compare different proposals for GIS systems, to make well-informed decisions about the preferred proposal and, if necessary, to find their own solutions to given problems with spatial reference. Students should develop an understanding of the current state of research in spatial information systems. With appropriate supervision, students should be able to tackle research problems.
Content	The course covers advanced basics of spatial information systems (GIS), such as acquisition, organization, analysis and presentation of data with spatial reference. The lab classes and the individual project lead to a deeper understanding of GIS workflows, tools and extensions and should turn knowledge into practice. The core topics are: Acquisition of spatial data, Data types and dimensions of geo-objects, Primary and secondary spatial reference, Coordinate reference systems and map projections, Acquisition of geo-spatial base data and available online resources, Spatial data management, Object-relational database management systems, Efficient tree-structures for spatial data, Object-oriented data modeling, Graphical GIS modeling in UML, 3D city models, Spatial data analysis, Spatial interpolation and analysis of vector-based geo-objects, Route planning and traveling salesman problem, Presentation of spatial data, Cartographic visualization and generalization, GIS applications
Teaching and learning forms/ Didactic concept	Lectures and practical sessions combined with individual and group-based studies related to theoretical and practical aspects of the course contents. Practical sessions can include project-oriented and laboratory work based on concrete problems. Theoretical aspects can include reading, understanding and presenting recent publications. Classes consist of one 90-minute lecture per week, one 90-minute practical session every two weeks and a final small project during the semester. Postdoctoral researchers, doctoral students and teaching assistants supervise students and are available for intensive discussion and feedback.

Literature and special information	Course material: www.uni-weimar.de/en/media/chairs/computer-science-department/computer-vision/teaching/spatial-information-systems-gis/ Literature: M. de Smith, M. Goodchild and D. Longley: Geospatial Analysis, 2018. R. Bill: Grundlagen der Geo-Informationssysteme, 6. Edition, Wichmann, 2016. N. Bartelme: Geoinformatik – Modelle, Strukturen, Funktionen, 4. Auflage, Springer, 2005. N. de Lange: Geoinformation in Theorie und Praxis, 2. Auflage, Springer, 2006.
Courses with SWS / ECTS	This module is comprised of: “Spatial information systems (GIS)” (Lecture, 2 SWS) “Spatial information systems (GIS)” (Exercise, 1 SWS) “Spatial information systems (GIS)” (Project, 1 SWS)

Title	Stochastic Simulation Techniques and Structural Reliability	
Semester (optional)		
Frequency	Once in a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105 (including project work)
	Exam preparation	60
Language of instruction	English	
Module coordinators	Prof. Dr. rer. nat. Tom Lahmer - Chair of Optimization and Stochastics	
Usability / Type of module	Compulsory module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in the subject area “Simulation and Validation” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Participation in Module „Applied Mathematics and Stochastics”	
Recommended requirements for participation	Basics in “Probability Theory” are recommended.	
Required examination (including partial exams if applicable)	Type	1 written or oral exam + 1 Project report = 3ECTS. Optionally: One project valid 3 ECTS.
	Requirements for exam registration	Submission of assignments
	Language	English
	Duration / Scope	90 min.
	Weighting	Project Report (30 % of 3 ECTS)
Written exam (70 % of 3 ECTS)		
Optionally one project (100 % of extra 3 ECTS)		

Target qualification	Soils, rocks and materials like concrete are in the natural state among the most var-iable of all engineering materials. Engineers need to deal with this variability and make decisions in situations of little data, i.e. under high uncertainties. The course aims in providing the students with techniques state of the art in risk assessment (structural reliability) and stochastic simulation. While working in teams in the computer classes students additionally train their skills in co-operating and working in teams with members of different knowledge levels.
Content	The course topics comprise - (a very brief review) of probability theory - discrete and continuous random processes and fields - estimation of statistical parameters - stochastic simulation techniques (Monte Carlo Samplings) - reliability-based design - sensitivity analysis - structural safety - Risk assessment and stochastic modeling in practice The lecture consists of weekly lectures by Prof. Tom Lahmer (Bauhaus University Weimar) throughout the semester
Teaching and learning forms/ Didactic concept	Lectures and practical sessions combined with individual and group-based studies related to theoretical and practical aspects of the course contents. Practical sessions can include project-oriented and laboratory work based on concrete problems. Theoretical aspects can include reading, understanding and presenting recent pub-lications. Classes consist of one 90-minute lecture and one 90-minute practical ses-sion per week during the semester. Postdoctoral researchers, doctoral students and teaching assistants supervise students and are available for intensive discussion and feedback.
Literature and special information	Fenton and Griffith „Risk Assessment in Geotechnical Engineering”, Bucher: „Computational Analysis of Randomness in Structural Mechanics”
Courses with SWS / ECTS	This module is comprised of: “Stochastic simulation techniques and Structural reliability” (Lecture, 2 SWS), “Stochastic simulation techniques and Structural reliability” (Exercise, 2 SWS) + Project work

Title	Structural Dynamics	
Semester (optional)	1, 2, 3 or 4	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 6 SWS	
Workload	In-class study / online-study	70
	Self-study	80
	Exam preparation	30
Language of instruction	English	
Module coordinators	Dr.-Ing. habil. Zabel, Volkmar – Chair of Structural Analysis and Component Strength	
Usability / Type of module	Compulsory / compulsory elective module for the degree programme M.Sc. Natu-ral Hazards and Risks in Structural Engineering (NHRE) Compulsory elective module in the subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Fundamental knowledge on mechanics as common on Bachelor level	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	
	Language	English
	Duration / Scope	180 minutes (2 parts of each 90 minutes
	Weighting	

Target qualification	In the first part of the module, the students will obtain basic knowledge of structural dynamics, become able to understand the concepts of analyses in time and frequency domain for SDOF systems as well as the extension of these analyses to MDOF systems. Further, they will be able to solve simple problems of structural dynamics by means of a numerical tool. of different kinds of dynamic loading on structures, obtain knowledge about the design of remedial measures. Further they will be able to solve more complex problems by means of a numerical tool. After passing the second part of the course, the students will be able to apply the concepts of SDOF and MDOF system analysis to practical problems, understand the principles of action of different kinds of dynamic loading on structures, obtain knowledge about the design of remedial measures. Further they will be able to solve more complex problems by means of a numerical tool.
Content	SDOF systems: free vibrations, harmonic, impulse and general excitation for undamped and damped systems, Impulse response function, frequency response function, base excitation, time step analysis: central difference and Newmark methods MDOF systems: modal analysis, modal superposition, modal damping, Rayleigh damping, Frequency response functions, state-space models Continuous systems: free and forced vibrations, travelling loads; Applications: machinery induced vibrations, earthquake excitation, wind induced vibrations, human induced vibrations
Teaching and learning forms/ Didactic concept	Lectures and practical sessions (tutorials) in classroom. Practical sessions in computer pool.
Literature and special information	Clough, Penzien: Dynamics of Structures, 2010 Chopra: Dynamics of Structures, 2015
Courses with SWS / ECTS	This module is comprised of: “Fundamentals of Structural Dynamics” (Lecture and exercises, 3 SWS) “Applied Structural Dynamics” (Lecture and exercises, 3 SWS)

IV. Computer Science Methods

Methods for the visualization as well as searching and analyzing large amounts of data, which can e.g. be acquired during extensive simulations, are taught in the subject area 'Computer Science Methods'. In this context, machine learning algorithms can be used for computer-assisted decisions and as surrogate models for computer-intensive simulation models. Modern methods of modular software development are trained as well. Furthermore, methods of image acquisition, recognition and processing are presented that can be used to validate models and support visualizations.

Module Title	**Module Coord.**	**ECTS/SWS**	**Sem.**
Computer Graphics: Fundamentals of Imaging	C. A. Wüthrich	6 ECTS / 4 SWS	SS
Formal Methods for Software Engineering	J. O. Ringert	6 ECTS / 4 SWS	WS
Generative Software Engineering	J. O. Ringert	6 ECTS / 4 SWS	SS
Image Analysis and Object Recognition	V. Rodehorst	6 ECTS / 4 SWS	SS
Introduction to Machine Learning and Data Mining	B. Stein	6 ECTS / 3 SWS	WS
Photogrammetric Computer Vision	V. Rodehorst	6 ECTS / 4 SWS	WS
Search Algorithms	B. Stein	6 ECTS / 3 SWS	WS
Visualization	B. Fröhlich	6 ECTS / 3 SWS	SS

Title	Computer Graphics: Fundamentals of Imaging	
Semester (optional)	1	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Wüthrich, Charles A. - Chair of Computer Graphics	
Usability / Type of module	Compulsory elective module in the subject area “Visualization and Data Science” for the de-gree programme M.Sc. Digital Engineering Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media	
Formal requirements for participation		
Recommended requirements for participation	basic knowledge in linear algebra	
Required examination (including partial exams if applicable)	Type	Assignments and written test
	Requirements for exam registration	45
	Language	English
	Duration / Scope	105
	Weighting	30

Target qualification	Modern Digital Imaging Devices are ubiquitous nowadays. The goal of this course is to understand the principles of imaging and to be able to conceive, design and implement systems relevant for imaging. Students should understand the following topics: - The physics of optics and its associated quantities, light and radiometry, geometrical optics and lenses. - Human vision, photometry, colorimentry, color spaces. - Photographic rules, composition, aperture, field of view. - Analog and digital capturing devices, light sensors. - Advanced methods and functions for assessing image quality. - Enhancing algorithms to overcome and correct capturing shortcomings. - Factors leading to imaging quality. At the end of the course, they should have mastered the conception, design and implementation of imaging software for both generic digital light sensors and digital photography.
Content	Light and Radiomentry, Human Vision, Photometry, Colorimentry. Advanced Color Spaces, Geometrical Optics and Lenses, Optical Equations for Lense Systems, Photographic Composition, quantities used in photography, Analog Photography, Digital Sensors, Image Enhancing, Debayering Filtering, Edge Enhancement, Image Quality Assessment, Use of Fourier, Cosine and Wavelet Transforms in Imaging.
Teaching and learning forms/ Didactic concept	Lecture and Exercitations. Implementation of various algorithms in the Ex-ercitation. Written final Exam.
Literature and special information	Zhou, W and Bovik, A.C., Image Quality Assessment, Morgan and Claypool; Hsien-Che Lee, Fundamentals of Color Imaging, Cambridge University Press
Courses with SWS / ECTS	This module is comprised of: "Computer Graphics: Fundamentals of Imaging" (Lecture, 2 SWS) "Computer Graphics: Fundamentals of Imaging" (Seminar, 2 SWS)

Title	Formal Methods for Software Engineering	
Semester (optional)	3	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	60
	Self-study	90
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Jan Oliver Ringert - Software Engineering	
Usability / Type of module	Elective module in the subject area “Visualization and Data Science” for the degree programme M.Sc. Digital Engineering Elective module for the degree programme M.Sc. Computer Science for Digital Media	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge in Software Engineering	
Required examination (including partial exams if applicable)	Type	Written exam or oral exam
	Requirements for exam registration	Successful participation and submission of the exercises.
	Language	English
	Duration / Scope	90 - 105 min
	Weighting	
Target qualification	After completion students will be able to • Model problems in different formalisms • Analyze software models using formal method tools • Evaluate formal methods for software engineering problems	

Content	Formal methods are rigorous techniques for the mathematical analysis of software and hardware systems. This course introduces aspects of formal methods with applications to software engineering problems. The topics covered in the course include: • Introduction to Formal Methods • Formal methods tools, e.g., o SMT solvers on the example of Z3 o Relational models and the Alloy Analyzer o Model Checking using SMV • Applications of formal methods in practice
Teaching and learning forms/ Didactic concept	Interactive lectures with discussions and practical work. Exercises will practice the concepts taught concepts so that theory and practice come hand in hand. As teaching concepts, we will use audience response system, buzz groups, randomized team competitions, and others.
Literature and special information	
Courses with SWS / ECTS	This module is comprised of: “Formal Methods for Software Engineering” (Lectures, 2 SWS) “Formal Methods for Software Engineering” (Exercises, 2 SWS

Title	Generative Software Engineering	
Semester (optional)	2	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	60
	Self-study	90
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Jan Oliver Ringert - Software Engineering	
Usability / Type of module	Elective module in the subject area “Visualization and Data Science” for the degree programme M.Sc. Digital Engineering Elective module for the degree programme M.Sc. Computer Science for Digital Media	
Formal requirements for participation		
Recommended requirements for participation	basic knowledge in Software Engineering	
Required examination (including partial exams if applicable)	Type	Written exam or oral exam
	Requirements for exam registration	Successful participation and submission of the exercises.
	Language	English
	Duration / Scope	90 - 105 min
	Weighting	

Target qualification	After completion students will be able to • Contrast different modelling languages and chose based on purpose • Analyze model consistency • Evaluate and apply code generators • integrate generated code in software projects • create and analyze temporal specifications • synthesize software from temporal specifications • understand domain specific languages
Content	We introduce main approaches and techniques to generative software development. • Model Driven Engineering • Software Modeling languages for structure and behavior • Class Diagrams, Object Diagrams, OCL • Sequence Diagrams and State Machines • Software model consistency and semantics • Code Generation from class diagrams • Code generation from State Machines • Reactive Synthesis from temporal specifications • Software Product Lines • Domain Specific Languages
Teaching and learning forms/ Didactic concept	Interactive lectures with discussions and practical work. Exercises will practice the concepts taught concepts so that theory and practice come hand in hand. As teaching concepts, we will use audience response system, buzz groups, randomized team competitions, and others.
Literature and special information	
Courses with SWS / ECTS	This module is comprised of: “Generative Software Engineering” (Lectures, 2 SWS) “Generative Software Engineering” (Exercises, 2 SWS

Title	Image Analysis and Object Recognition	
Semester (optional)	2 or 4	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Volker Rodehorst - Computer Vision in Engineering	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media Compulsory elective module in the subject area "Visualization and Data Science" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge in linear algebra, basic knowledge in machine learning, basic programming knowledge	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	Successful completion of the lab classes
	Language	English
	Duration / Scope	90 minutes
	Weighting	examination 100%, successful completion of the project

Target qualification	The goal is to understand the principles, methods and applications of computer vision from image processing to image understanding. Students should be able to apply the above topics for solving computer vision problems. Furthermore, they should appreciate the limits and constraints of the above topics. Students should be able formalise and generalise their own solutions using the above concepts of image processing, image analysis and object recognition. Students should master concepts and approaches such as application-specific feature extraction, generation, learning and application of models for object recognition, data-driven and model-driven processing strategies, in order to tackle computer vision problems and their application to digital engi-neering. They should be able to understand proposed image analysis methods, to compare different proposals for object recognition systems, to make well-informed decisions about the preferred proposal and, if necessary, to find their own solutions to given computer vision problems. Students should develop an understanding of the current state of research in image analysis and object recognition. With appropriate supervision, students should be able to tackle research problems.
Content	Image processing, feature extraction, shape detection, object recognition, machine learning, image representation and enhancement, morphological and local filter operators, corner and edge detection, filtering in frequency domain, shape detection with generalized Hough transform and Fourier descriptors, object recognition with Viola-Jones, SIFT-based voting and implicit shape models, segmentation and clustering of image regions, deep learning for visual recognition, pattern recognition methods and strategies.
Teaching and learning forms/ Didactic concept	Lectures and practical sessions combined with individual and group-based studies related to theoretical and practical aspects of the course contents. Practical sessions can include project-oriented and laboratory work based on concrete problems. Theoretical aspects can include reading, understanding and presenting recent publications. Classes consist of one 90-minute lecture per week, one 90-minute practical session every two weeks and a final small project during the semester. Postdoctoral researchers, doctoral students and teaching assistants supervise students and are available for intensive discussion and feedback.

Literature and special information	Course material: www.uni-weimar.de/en/media/chairs/computer-vision/teaching/image-analysis-and-object-recognition/ Literature: B. Jähne: Digital image processing, Springer, 2022. | R.C. Gonzalez and R.E. Woods: Digital image processing, Pearson, 2017. | R. Szeliski: Computer vision: algorithms and applications, 2. Edition, Springer, 2022. | D. Forsyth and J. Ponce: Computer vision: a modern approach, Pearson, 2012. | R.O. Duda, P.E. Hart and D.G. Stork: Pattern classification, Wiley, 2000. | C.M. Bishop: Pattern recognition and machine learning, Springer, 2007. | I. Goodfellow et al.: Deep learning, MIT Press, 2016.
Courses with SWS / ECTS	The module consists of the following courses: “Image Analysis and Object Recognition” (Lecture, 2 SWS) “Image Analysis and Object Recognition” (Lab work, 1 SWS) “Image Analysis and Object Recognition” (Project, 1 SWS)

Title	Introduction to Machine Learning and Data Mining	
Semester (optional)	1 or 3	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 3 SWS	
Workload	In-class study / online-study	34
	Self-study	116
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Benno Stein - Intelligent Information Systems	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media Compulsory elective module in the subject area “Visualization and Data Science” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	basic knowledge in linear algebra; basic knowledge in programming	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	Active participation in lab classes
	Language	English
	Duration / Scope	90 minutes
	Weighting	

Target qualification	Given a task and a performance measure, a computer program (and hence a machine) is said to learn from experience, if its performance at the task improves with the experience. In this course students will learn to understand machine learning as a guided search in a space of possible hypotheses. The mathematical means to formulate a particular hypothesis class determines the learning paradigm, the discriminative power of a hypothesis, and the complexity of the learning process. Aside from theoretical and algorithmic foundations of supervised learning, hand-on experience in machine learning implementation is taught. Students should understand the following concepts and theories: classifier design, hypothesis space, model bias, regression for classification, logistic regression, effectiveness computation, loss function derivation, gradient descent, regularization, neural networks, decision trees, impurity functions, Bayesian learning. Students should be able formalize real-world decision tasks as machine learning problems. They should be able to apply the above concepts and theories for solving concrete learning problems. In particular, they should be able to choose the appropriate learning paradigm within a concrete setting. Students should master concepts and approaches such as classifier programming, classifier application, classifier evaluation, the selection of model function types, model selection and assessment principles in order to tackle machine learning problems for different feature spaces structures. They should be able to analyze machine learning problems, to compare different learning algorithms, and to make well-informed decisions about the preferred learning paradigm. Students should develop an understanding of the current developments in machine learning. With appropriate supervision, they should be able to tackle research problems.
Content	Learning settings, Rule-based Learning, Linear regression, Foundations of evaluation, Logistic regression, Neural networks, Decision trees, Bayesian learning
Teaching and learning forms/ Didactic concept	The lecture introduces concepts, algorithms, and theoretical backgrounds. The accompanying lab treats both theoretical and applied tasks to deepen the understanding of the field. Team work (2-3 students) is appreciated in order to discuss the own learning progress, to improve skills in preparing and presenting the solution of exercises, as well as to practice team-based problem solving techniques.

Literature and special information	Course material: https://webis.de/lecturenotes.html#machine-learning Tools: NumPy, scikit-earn, R, SciPy, GNU Octave Literature: C.M. Bishop. Pattern Recognition and Machine Learning | T. Hastie, R. Tibshirani, J. Friedman. The Elements of Statistical Learning | T. Mitchell. Machine Learning
Courses with SWS / ECTS	This module is comprised of: “Introduction to Machine learning” (Lecture, 2 SWS) “Introduction to Machine Learning” (Exercise, 1 SWS)

Title	Photogrammetric Computer Vision	
Semester (optional)	1 or 3	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr.-Ing. Volker Rodehorst - Computer Vision in Engineering	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media Compulsory elective module in the subject area “Visualization and Data Science” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge in linear algebra; basic knowledge in programming;	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	Successful completion of the lab classes
	Language	English
	Duration / Scope	90 minutes
	Weighting	examination 100%, successful completion of the project

Target qualification	The course introduces the basic concepts of sensor orientation and 3D reconstruction. The goal is an understanding of the principles, methods and applications of image-based measurement. Students should learn the following topics: Homogeneous representation of points, lines and planes, Planar and spatial transformations, Estimation of relations using a direct linear transformation (DLT), Modelling and interpretation of a camera, Optical imaging with lenses, Epipolar geometry and multiview tensors, Global bundle adjustment, Robust parameter estimation and Image matching strategies. Students should be able to apply the above topics for solving photogrammetric problems. Furthermore, they should appreciate the limits and constraints of the above topics. Students should be able formalise and generalise their own solutions using the above concepts of sensor orientation and 3D reconstruction. Students should master concepts and approaches such as: Algebraic projective geometry, Reconstruction and inversion of the imaging geometry and Correspondence problem. In order to tackle problems in photogrammetry and its application to digital engineering, they should be able to understand proposed sensor orientation problems, to compare different proposals for image-based 3D reconstruction systems, to make well-informed decisions about the preferred proposal and, if necessary, to find their own solutions to given problems in photogrammetry. Students should develop an understanding of the current state of research in photogrammetric computer vision. With appropriate supervision, students should be able to tackle research problems.
Content	Image-based 3D reconstruction, Homogeneous coordinates, Algebraic projective 2D and 3D geometry, Camera calibration, Sensor orientation using multi-view geometry, Stereo image matching
Teaching and learning forms/ Didactic concept	Lectures and practical sessions combined with individual and group-based studies related to theoretical and practical aspects of the course contents. Practical sessions can include project-oriented and laboratory work based on concrete problems. Theoretical aspects can include reading, understanding and presenting recent publications. Classes consist of one 90-minute lecture per week, one 90-minute practical session every two weeks and a final small project during the semester. Postdoctoral researchers, doctoral students and teaching assistants supervise students and are available for intensive discussion and feedback.

Literature and special information	Course material: www.uni-weimar.de/en/media/chairs/computer-vision/teaching/photogrammetric-computer-vision/ Literature: W. Förstner and B.P. Wrobel: Photogrammetric computer vision – statistics, geometry, orientation and reconstruction, Springer, 2016. R. Hartley and A. Zisserman: Multiple view geometry in computer vision, 2. Edition, Cambridge University Press, 2003. O. Faugeras and Q.-T. Luong: The geometry from multiple images, MIT Press, 2004. C. McGlone, E. Mikhail and J. Bethe: Manual of photogrammetry, 6. Edition, ASPRS, 2013. R. Szeliski: Computer vision: algorithms and applications, 2. Edition, Springer, 2022.
Courses with SWS / ECTS	The module consists of the following courses: “Photogrammetric Computer Vision” (Lecture, 2 SWS) “Photogrammetric Computer Vision” (Lab, 1 SWS) “Photogrammetric Computer Vision” (Project, 1 SWS)

Title	Search Algorithms	
Semester (optional)	1 or 3	
Frequency	Once a year in the winter semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 3 SWS	
Workload	In-class study / online-study	34
	Self-study	116
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Benno Stein - Intelligent Information Systems	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media Compulsory elective module in the subject area “Visualization and Data Science” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Algorithms and Data Structures; basic knowledge in programming	
Required examination (including partial exams if applicable)	Type	Written exam
	Requirements for exam registration	Active participation in lab classes
	Language	English
	Duration / Scope	90 minutes
	Weighting	

Target qualification	The course will introduce search algorithms as a means to solve combinatorial problems such as constraint satisfaction and optimization problems. Tackling such problems by a machine often follows a two-step approach: (1) definition of a space of solution candidates plus (2) intelligent exploration of this space. We will cover the modeling of search problems, basic (uninformed) search algorithms, informed search algorithms, as well as hybrid combinations. A special focus will be put on heuristic search approaches. Students should understand the following concepts and theories: State space versus problem reduction space, Uninformed search, Weight functions, Cost measures, Informed search, Admissibility of search algorithms, Search monotonicity and consistency Students should be able to model a search space by selecting the appropriate representation principle and by devising an encoding for partial solution bases. They should understand and describe how different search algorithms will explore the search space differently. With regard to informed search algorithms they should understand the principle of admissible search and to prove basic properties of the search algorithms (completeness, soundness, adminissibility). The students will learn to analyze the nature of search problems, this way being able to devise adequate search space representations, (heuristically) inform an uninformed strategy, develop admissible search strategies, combine informed with uninformed strategies, prove important properties such as admissibility or monotonicity. Students should eventually be able to tackle non-trivial search and constraint satisfaction problems and its application to Digital Media. In this regard they should be able to make well-informed decisions and explain their solution approach, considering the theoretical background. With appropriate supervision, students should be able to tackle research problems. Students should develop an understanding of the current developments of the Semantic Web. With appropriate supervision, they should be able to tackle research problems.
Content	Search examples, Search space representations, Algorithms for uninformed search, Hybrid search algorithms, Algorithms for informed search, Theoretical properties of search algorithms

Teaching and learning forms/ Didactic concept	The lecture introduces concepts, algorithms, and theoretical backgrounds. The accompanying lab treats both theoretical and applied tasks to deepen the understanding of the field. Team work (2-3 students) is appreciated in order to discuss the own learning progress, to improve skills in preparing and presenting the solution of exercises, as well as to practice team-based problem solving techniques.
Literature and special information	Course material: https://webis.de/lecturenotes.html#search Literature: Edmund K. Burke, Graham Kendall. Search Methodologies |Nils J. Nilsson. Artificial Intelligence: A New Synthesis | Judea Pearl. Heuristics | Stuart Russel, Peter Norvig. Artificial Intelligence: A Modern Approach
Courses with SWS / ECTS	This module is comprised of: “Search Algorithms” (Lecture, 2 SWS) “Search Algorithms” (Exercise, 1 SWS)

Title	Visualization	
Semester (optional)	2 or 4	
Frequency	Once a year in the Summer semester	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 3 SWS	
Workload	In-class study / online-study	34
	Self-study	106
	Exam preparation	30
Language of instruction	English	
Module coordinators	Prof. Dr. Bernd Fröhlich - Professor of Virtual Reality and Visualization	
Usability / Type of module	Compulsory elective module in the subject area “Computer Science Methods” for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Fundamental programming knowledge at bachelor level from a computer science related degree or acquired by successful participation in the course Object-oriented Modeling and Programming in Engineering (subject area Fundamentals)	
Recommended requirements for participation		
Required examination (including partial exams if applicable)	Type	Coursework (written or via presentations) in combination with a final exam (written or oral).
	Requirements for exam registration	50% of the achievable points for coursework
	Language	English
	Duration / Scope	30-45 minutes (oral) or 90-150 minutes (written).
	Weighting	50% coursework and 50% final exam

Target qualification	The students will have an overview of the fields information visualization and scientific visualization. They know state-of-art selection of visualization techniques for data from different sources and of different types. They are able to assess selected techniques for appropriateness and effectiveness, and are able to justify choices of methods. Furthermore, students are able to classify datasets into various categories and are able to design, implement, customize and evaluate appropriate visualization techniques and their interactive interfaces based on the acquired knowledge.
Content	The core topics are: - Information visualization of multi-attribute data, hierarchical data, graphs, time series, cartographic and set-based data - Scientific visualization concepts and techniques for visualizing volumetric and vector-based data as well multi-resolution approaches for dealing with very large models The lab classes focus on implementing, testing and evaluating the various algorithms and approaches presented during the lectures using state-of-the-art software frameworks.
Teaching and learning forms/ Didactic concept	Lectures are combined with project-oriented and lab work based on concrete problems (problem-based learning approach). Classes in this module consist of a 90min lecture and 45min practical session per week during the semester. Coursework consists of overall 5 or at most 6 assignments distributed over the semester. Various approaches presented in lectures will be studied, in part practically through labs and assignments as well as a short project as the final assignment. Lab classes focus on implementing, testing and evaluating the visualization approaches presented during the lectures. Postdoctoral researchers, doctoral students and teaching assistants are supervising the students. They are available for intensive discussions and immediate feedback. This module conveys method skills and theoretical and practical backgrounds, which are assessed via an oral or written exam. Practical skills and implementation competencies are assessed via assignments during the lab class.
Literature and special information	Literature: Munzner, T: Visualization Analysis and Design: Principles, Techniques, and Practice
Courses with SWS / ECTS	This module is comprised of: “Visualization” (Lecture, 2 SWS) “Visualization” (Lab class, 1 SWS)

V. Profile Lines

In the following the profile lines and related modules are listed.

Module	Dig. Eng.	Structures and Materials ($\geq$ 60 ECTS)	Mobility and Transport ($\geq$ 60 ECTS)
Fundamentals			
Algorithms and Data Structures	6 ECTS		
Applied Mathematics and Stochastics	6 ECTS		
Introduction to Mechanics	6 ECTS		
Mathematics for data science	6 ECTS		
Object-oriented Modeling and Programming in Engineering	6 ECTS		
Software Engineering	6 ECTS		
Statistics	6 ECTS		
Structural Engineering Models	6 ECTS		
Required ECTS[1]	18		

[1] Please look at your stipulations for required Fundamentals

Module	Dig. Eng.	Structures and Materials (≥ 60 ECTS)	Mobility and Transport (≥ 60 ECTS)
Engineering Methods			
Advanced Building Information Modeling	6 ECTS		
Complex dynamics	6 ECTS		
Computer models for physical processes – from observation to simulation	6 ECTS		
Design and Interpretation of Experiments	6 ECTS	6 ECTS	
Experimental Structural Dynamics	6 ECTS	6 ECTS	
Finite Element Methods	6 ECTS	6 ECTS	
Indoor Environmental Modeling	6 ECTS		
Introduction to Mobility and Transport	6 ECTS		6 ECTS
Macroscopic Transport Modeling	6 ECTS		6 ECTS
Microscopic Traffic Simulation	6 ECTS		6 ECTS
Modelling of Steel Structures and Numerical Simulation	6 ECTS	6 ECTS	
Optimization	6 ECTS		
Simulation Methods in Engineering	6 ECTS		6 ECTS
Spatial Information Systems (GIS)	6 ECTS		6 ECTS
Stochastic Simulation Techniques and Structural Reliability	6 ECTS	6 ECTS	
Structural Dynamics	6 ECTS	6 ECTS	
Required ECTS	36	≥18	≥18
Computer Science Methods			
Computer Graphics: Fundamentals of Imaging	6 ECTS		
Formal Methods for Software Engineering	6 ECTS		
Generative Software Engineering	6 ECTS		
Image Analysis and Object Recognition	6 ECTS	6 ECTS	6 ECTS
Introduction to Machine Learning and Data Mining	6 ECTS	6 ECTS	6 ECTS
Photogrammetric Computer Vision	6 ECTS		6 ECTS
Search Algorithms	6 ECTS		
Visualization	6 ECTS	6 ECTS	6 ECTS
Required ECTS	18	≥12	≥12

Module	Dig. Eng.	Structures and Materials (≥ 60 ECTS)	Mobility and Transport (≥ 60 ECTS)
Electives, Project, Master Module			
Electives	12 ECTS	≤ 12 ECTS	≤ 12 ECTS
Project[2]	12 ECTS	0 or 12 ECTS	0 or 12 ECTS
Master Module [3]	24 ECTS	24 ECTS	24 ECTS
Required ECTS	48	≥24	≥24
Sum	120	≥60	≥60

[2] If the project is related to your profile line, it can be counted for that.
[3] The Master Module **must** be related to your profile line.

VI. Example programme schedules

The curriculum:

Name	*ECTS*
Fundamentals (F)	18
Engineering Methods (EM)	36
Computer Science Methods (CSM)	18
Elective Modules	12
Project	12
Master Module	24
Total	120

Example 1. Background: Bachelor in Engineering with Start in winter semester. Without specific specialization. Electives are written in italic.

Module	Sem. 1 (WS)		Sem. 2 (SS)		Sem. 3 (WS)		Sem. 4 (SS)	
	SWS	ECTS	SWS	ECTS	SWS	ECTS	SWS	ECTS
Object-oriented Modeling and Program-ming in Engineering	4	6						
Computer models for physical processes – from observation to simulation	4	6						
Design and Interpretation of Experiments	6	6						
Structural Dynamics	6	6						
Introduction to Machine Learning and Data Mining	3	6						
Algorithms and Data structures			4	6				
Software Engineering			3	6				
Advanced Building Information Modeling			4	6				
Complex dynamics			4	6				
Visualization			3	6				
English C1 / German A1			2	3				
Spatial Information Systems (GIS)					4	6		
Photogrammetric Computer Vision					4	6		
Project					8	12		
Research Master Module					2	3		
Indoor Environmental Modeling							4	6
Image Analysis and Object Recognition							4	6
Master thesis and defense							14	21
Total	20	30	21	33	18	27	22	33

Example 2. Background: Bachelor in Computer Science with Start in summer semester. Without specific specialization. Electives are written in italic.

Module	Sem. 1 (SS)		Sem. 2 (WS)		Sem. 3 (SS)		Sem. 4 (WS)	
	SWS	ECTS	SWS	ECTS	SWS	ECTS	SWS	ECTS
Software Engineering	4	6						
Statistics	4	6						
Advanced Building Information Modeling	4	6						
Simulation Methods in Engineering	4	6						
Generative Software Engineering	4	6						
Introduction to Mechanics			4	6				
Finite Element Methods			6	6				
Structural Dynamics			6	6				
Introduction to Machine Learning and Data Mining			3	6				
Photogrammetric Computer Vision			4	6				
Modelling of Steel Structures and Numerical Simulation					4	6		
Stochastic Simulation Techniques and Structural Reliability					4	6		
Image Analysis and Object Recognition					4	6		
Project					8	12		
Research Master Module					2	3		
Search Algorithms							3	6
Master thesis and defense							14	21
Total	20	30	21	30	22	33	17	27

Example PL "Structures and Materials". Background: Bachelor in Engineering with Start in winter semester. Electives are written in italic. PL related modules are bold.

Module	Sem. 1 (WS)		Sem. 2 (SS)		Sem. 3 (WS)		Sem. 4 (SS)	
	SWS	ECTS	SWS	ECTS	SWS	ECTS	SWS	ECTS
Object-oriented Modeling and Program-ming in Engineering	4	6						
Finite Element Methods	6	6						
Design and Interpretation of Experiments	6	6						
Structural Dynamics	6	6						
Introduction to Machine Learning and Data Mining	3	6						
Algorithms and Data structures			4	6				
Software Engineering			3	6				
Advanced Building Information Modeling			4	6				
Modelling of Steel Structures and Numerical Simulation			4	6				
Visualization			3	6				
English C1 / German A1			2	3				
Spatial Information Systems (GIS)					4	6		
Photogrammetric Computer Vision					4	6		
Project					8	12		
Research Master Module					2	3		
Indoor Environmental Modeling							4	6
Image Analysis and Object Recognition							4	6
Master thesis and defense							14	21
Accumulated ECTS for Profile Line	24		36		51		78	
Total	20	30	21	33	18	27	22	33

Example PL "Mobility and Transport". Background: Bachelor in Computer Science with Start in Summer Semester. Electives are written in italic. PL related modules are bold.

Module	Sem. 1 (SS)		Sem. 2 (WS)		Sem. 3 (SS)		Sem. 4 (WS)	
	SWS	ECTS	SWS	ECTS	SWS	ECTS	SWS	ECTS
Software Engineering	4	6						
Statistics	4	6						
Advanced Building Information Modeling	4	6						
Simulation Methods in Engineering	4	6						
Generative Software Engineering	4	6						
Introduction to Mechanics			4	6				
Finite Element Methods			6	6				
Applied Finite Element Methods			2	3				
Introduction to Mobility and Transport			6	6				
Introduction to Machine Learning and Data Mining			3	6				
Photogrammetric Computer Vision			4	6				
Macroscopic Transport Modeling					4	6		
Microscopic Traffic Simulation					4	6		
Image Analysis and Object Recognition					4	6		
Project					8	12		
Research Master Module					2	3		
Search Algorithms							3	6
Master thesis and defense							14	21
Accumulated ECTS for Profile Line	6		24		57		78	
Total	20	30	21	30	22	33	17	27