Module Handbook
M.Sc. Digital Engineering

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Contents

I. Curriculum

The Master's degree course in Digital Engineering lasts 4 semesters and comprises 120 credit points (CP).
The Compulsive Electoral Modules are assigned to four different subject areas, which deal with the following aspects of Digital Engineering: "Fundamentals", "Modeling", "Simulation & Validation" and "Visualization & Data Science". From each subject area the students choose and complete modules with a total of 18 CP.
As part of the program admission two 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 courses from other departments of the Faculties of Media or Civil Engineering or language courses, thus acquiring additional knowledge and skills.
The research project not only aims to expand relevant specialist skills, but also cover interdisciplinary projects. Beyond that, they serve 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 four months in which students must produce the thesis itself. The final stage of the Mastermodule is the defense of the Master's thesis.

Name	*Credit Points*
Fundamentals (F)	18
Modelling (M)	18
Simulation and Validation (SaV)	18
Visualization and Data Science (VaDS)	18
Elective Modules	12
Project	12
Mastermodule	24
Total	120

Curriculum - Example

Course	Semester 1		Semester 2		Semester 3		Semester 4	
	cred.h.	CP	cred h.	CP	cred.h.	CP	cred. h.	CP
Individually assigned Module (F)	3	6						
Individually assigned Module (F)	6	6						
Compulsory Elective Module (F)	4	6						
Compulsory Elective Module (M)	4	6						
Compulsory Elective Module (M)	2	3						
Compulsory Elective Module (M)	1	3						
Compulsory Elective Module (M)			4	6				
Compulsory Elective Module (SaV)			4	6				
Compulsory Elective Module (SaV)			4	6				
Compulsory Elective Module (VaDS)			3	6				
Compulsory Elective Module (VaDS)			3	6				
Compulsory Elective Module (VaDS)					3	6		
Projekt					-	12		
Elective Module					4	6		
Elective Module					2	3		
Research Mastermodule (not rated)					-	3		
Elective Module							2	3
Compulsory Elective Module (SaV)							4	6
Masterthesis and Defense							-	21
Total	20	30	18	30	9	30	6	30

II. Subject Area “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 Coordinator	ECTS / SWS	Semester
Algorithms and Datastructures	Wüthrich	6 ECTS / 4 SWS	WS
Applied Mathematics and Stochastics	Gürlebeck/Lahmer	6 ECTS / 6 SWS	WS
Nonlinear Continuum Mechanics	T. Rabczuk	6 ECTS / 4 SWS	WS
Numerical Linear Algebra	Gürlebeck/Legatiuk	6 ECTS / 4 SWS	WS
Software Engineering	N. Siegmund	6 ECTS / 3 SWS	WS
Statistics	Illge	6 ECTS / 4 SWS	SS
Structural Dynamics	V. Zabel	6 ECTS / 6 SWS	WS
Structural Engineering Models	C. Könke	6 ECTS / 3 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 coordinator(s)	Prof. Dr. Wüthrich, Charles A. - Chair of Computer Graphics	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering Compulsory elective module for the degree programme B.Sc. Medieninformatik Elective module for the degree programme B.F.A. Medienkunst/Mediengestaltung Elective module for the degree programme M.F.A. Medienkunst/Mediengestaltung	
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 qualifications	Successful participants master the following concepts and are able to explain them to others: Fundamentals Methods for the organisation of data. Analysis and classification of the complexity of an Algorithm (best case-average case-worst case) Search algorithms, sorting algorithms, algorithms on graphs, flux in networks. Divide and conquer, space partition algorithms. Geometric algorithms: convex hull, closest points problem. Random numbers, Multiplication of high order Polynomials, Fourier transforms, Linear and higher order regression, spline based approximation NP-hard problems: Hamilton cycles, Traveling Salesman Problem, undecidibility of formal logic, Halt problem of a Turing machine. Successful candidates are able to apply their knowledge and master the following: 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 implementation for solving different problems The development and implementation of new algorithms.	
Content	The lecture deals with the principle and the implementation of basic algorithms and	

	data structures. The course teaches among all, the Strings, geometric problems, graphs, mathematical algorithms and NP-complete problems. - Basic Data Structures, Complexity Analysis, Sorting Algorithms. - 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 learning forms/ Didactic concept	Lecture and Exercitations. Implementation of various algorithms in the Exercitation. Written final Exam.
Literature and special in-formation	R. Sedgewick, „Algorithmen" M. Goodrich and R. Tamassia ‚Algorithm Design"
Courses with SWS / ECTS (optional)	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 coordinator(s)	Prof. Dr. rer. nat. Klaus Gürlebeck – Chair of Applied Mathematics Prof. Dr. rer. nat. Tom Lahmer - Juniorprofessorship Optimization and Stochastics	
Usability / Type of module	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 qualifications	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 (MAPLE) 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 implementation in MAPLE will be studied. **Stochastics for risk assessment:** Introduction to probability theory with focus on situations characterized by low probabilities. Random events, discrete and continuous random variables and associated 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 e.g. MATLAB, Octave, Excel, R. Reliability Analysis of Systems. Catastrophic events + 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 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	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, Gürlebeck) "Stochastics" (Lecture, 2 SWS, Lahmer) "Applied Mathematics and Stochastics" (Exercises ,2 SWS, Gürlebeck/Lahmer)

Title	Nonlinear Continuum Mechanics	
Semester (optional)	1 or 3	
Frequency	Once a year in the winter semester, at least 30 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 coordinator(s)	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	Written/Oral Test (100%)
Target qualifications	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	Numerical Linear Algebra	
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	90
	Exam preparation	30
Language of instruction	English	
Module coordinator(s)	Prof. Dr. rer. nat. habil. Klaus Gürlebeck – Chair of applied Mathematics Dr. rer. nat. Dmitrii Legatiuk – Chair of applied Mathematics Dr. rer. nat. Sebastian Bock – Chair of applied Mathematics	
Usability / Type of module	Compulsory elective module in the subject area "Fundamentals" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Linear Algebra at Bachelor level	
Recommended requirements for participation	Participants should be familiar with Matlab or C++.	
Required examination (including partial exams if applicable)	Type	Written exam, project presentation
	Requirements for exam registration	Project
	Language	English
	Duration / Scope	2 hours (written exam)
	Weighting	The project is weighted with 1/3 and the written exam with 2/3 of the final grade.
Target qualifications	After the course the students will be able to discretize a given mathematical model and to build the corresponding linear or non-linear system of algebraic equations. They can implement such a system and/or understand a given implementation. They can analyse the obtained system, make a suitable choice of the solver and estimate the numerical costs and the error of the solution. Restrictions for the applicability depending on parameters of the mathematical / numerical model can be discussed.	
Content	Efficient solution of linear and non-linear systems of algebraic equations;, Discretization methods for different types of partial differential equations, Projection methods, stability and convergence, condition number, Direct solvers for sparse systems, Fixed-point theorem, iterative solvers: Total step method, single step method, gradient methods, relaxation methods, multiscale methods and a survey on other approaches, Eigenvalue problems, iterative solvers, Domain decomposition methods	
Teaching and learning forms/ Didactic concept	The topics will be presented in a lecture, deepened by exercises. In the second part of the semester the students work on individual projects.	
Literature and special information	R. Kress;Numerical Analysis Varga. Matrix iterative analysis. Hermann. Numerische Mathematik	
Courses with SWS / ECTS	This module is comprised of: "Numerical Linear Algebra" (Lecture, 2 SWS) "Numerical Linear Algebra" (Seminar, 2 SWS)	

Title	Software Engineering	
Semester (optional)	1	
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 coordinator(s)	Prof. Dr.-Ing. Norbert Siegmund - Chair of Intelligent Software Systems (Jun.-Prof. Florian Echtler)	
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
	Requirements for exam registration	Successful participation and submission of the exercises.
	Language	English
	Duration / Scope	90-105 min
	Weighting	
Target qualifications	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 exactly follow the lectures in implementing the concepts taught concepts so that theory and practice come hand in hand. As teaching concepts, we will use topic maps, 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., Pearson 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	45
	Self-study	105
	Exam preparation	30
Language of instruction	English	
Module coordinator(s)	Dr.rer.nat.habil. Illge, Reinhard – Chair of applied mathematics	
Usability / Type of module	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	None
	Language	English
	Duration / Scope	180 minutes
	Weighting	
Target qualifications	Students are taught in basic concepts and methods of statistics and stochastics. After 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 different problem-solving approaches or algorithms and to explain this choice in a comprehensible 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)	

Title	Structural Dynamics	
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 coordinator(s)	Dr.-Ing. Zabel, Volkmar – Chair of Structural Analysis and Component Strength	
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 "Fundamentals" for the degree programme M.Sc. Digital Engineering Elective module for the degree programme M.Sc. Bauingenieurwesen	
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 min.
	Weighting	Written exam (100 %)
Target qualifications	The students will obtain 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 become 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. Additionally, the students will be enabled to solve simple and 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, 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	The theory and knowledge about applications is presented in form of lectures including examples. Parallel to the lectures, weekly computer exercises are given to enable the students to implement the learned algorithms and methods numerically such that they develop a collection of numerical tools to solve problems in the field	

	of structural dynamics.
Literature and special in-formation	Recommended Literature: Clough, Penzien: Dynamics of Structures, 2010 Chopra: Dynamics of Structures, 2015
Courses with SWS / ECTS	This module is comprised of: “Structural Dynamics" (Lecture, 4 SWS) “Structural Dynamics" (Exercise, 2 SWS)

Title	Structural Engineering Models	
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 coordinator(s)	Prof. Dr.-Ing. Carsten Könke Professor 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 test
	Requirements for exam registration	2 home works accepted
	Language	English
	Duration / Scope	180 min
	Weighting	
Target qualifications	Student will be able to build an abstract model for structural engineering problem and to assess its restriction and quality. The student will be able to perform dimension reduction in structural engineering using concepts from structural mechanics. They will be capable of classify different types of civil engineering structures and to distinguish different principal load transfer processes. The student can classify linear/nonlinear problems and time variant/invariant problems in structural engineering.	
Content	Fundamental equations in structural mechanics for 1D, 2D and 3D structures, equilibrium equation, kinematic relation, constitute law, Method to establish the governing differential equations, Differences between geometric / physical linear and nonlinear problems, Classification of different types of structures: truss, beam, plate, shell problems	
Teaching and learning forms/ Didactic concept	Lectures and practical sessions (tutorials) in classroom.	
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: "Structural Engineering Models" (Lectures, 2 SWS) "Structural Engineering Models" (practical sessions, 2 SWS), optional tutorials	

III. Subject Area “Modelling”

In the subject area “Modeling”, methods for creating and working with engineering models are taught. Key objectives are the spatial, temporal and financial modeling at different abstraction levels, as well as the 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. In this context, techniques for optimizing and identifying input and output variables are also shown.

Module Title	**Module Coordinator**	**ECTS / SWS**	**Semester**
4- und 5D-Building Information Modeling (BIM)	Bargstädt	3 ECTS	?
Advanced Building Information Modeling	Koch / Tauscher	6 ECTS / 4 SWS	WS
Advanced Modelling - Calculation	Gürlebeck/Legatiuk	6 ECTS/ 4 SWS	SS
Collaborative Data Management	Koch	6 ECTS / 4 SWS	SS
Computer models for physical processes – from observation to simulation	Könke	6 ECTS / 4 SWS	WS
Introduction to Optimization	T. Lahmer	3 ECTS /3 SWS	WS
Modelling in the development process	C. Könke /C. Guist	3 ECTS / 2 SWS	SS, WS
Optimization in Applications	T. Lahmer	3 ECTS /3 SWS	SS

Title	4- and 5D-Building Information Modeling (BIM)	
Semester (optional)	Semester 2 or 4	
Frequency	once a year, minimum number of participants: 12	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	3 ECTS / 2 SWS	
Workload	In-class study / online-study	30
	Self-study	50 (including homework and term papers
	Exam preparation	10 (for finalizing term paper and oral presentation
Language of instruction	English / bilingual	
Module coordinator(s)	Prof. Dr.-Ing. Hans-Joachim Bargstädt - Chair of Construction Engineering and Management	
Usability / Type of module	Compulsory elective module in the subject area "Modelling" for the degree programme M.Sc. Digital Engineering.	
Formal requirements for participation		
Recommended requirements for participation	None	
Required examination (including partial exams if applicable)	Type	Homework Assignment
	Requirements for exam registration	Continuing work on assignments and software applications
	Language	English
	Duration / Scope	2 hrs. final presentation and group discussion
	Weighting	100 % for term paper
Target qualifications	Students will be able to use and manipulate Building Information Models in different formats. They will be able to derive specific information from complex digital building information models. They will experience to develop different model view applications.	
Content	The students will be introduced into the concept of Building Information Modeling. They will get to know some standard software in this area. They will perform modelling and analysis tasks on given building models. They will learn about data exchange interfaces like IFC (industry foundation classes)	
Teaching and learning forms/ Didactic concept	Short introduction by lecturer. A number of instructing video and online material. Regular meetings and input from lecturer. Presentation of developing and ongoing homework papers and software applicatioins.	
Literature and special information	Eastman et alii: Building Information Modeling Manual of different software applications (Autodesk, RIBiTwo, Tekla, Ceapoint) Different Video Tutorials from Bauhaus-Universität and from Internet	
Courses with SWS / ECTS	"4- and 5D-Building Information Modeling" (Online Course, 2 SWS)	

Title	Advanced Building Information Modelling	
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	135
	Exam preparation	0
Language of instruction	English	
Module coordinator(s)	Prof. Dr.-Ing. Koch, Christian – Chair of Intelligent Technical Design Dr.-Ing. Tauscher, Eike – Chair of Computing in Civil Engineering	
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. Bauingenieurwesen	
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 80%, presentation 20%
Target qualifications	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 modeling), 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, 2^{nd} edition, Wiley. Mortenson, M.E. (2006), Geometric Modeling, 3^{rd} edition, Instustrial Press. Shah, J.J., Mäntylä, M. (1995), Parametric and feature-based CAD/CAM – Concepts, Techniques and Applications. Liebich, T. (2009), IFC 2x Edition 3 Model Implementation Guide, Version 2.0.	

	Borrmann, A., König, M., Koch, C., Beetz, J. (2015), Building Information Modeling: Technologische Grundlagen und industrielle Praxis, Springer Vieweg.
Courses with SWS / ECTS	This module is comprised of: "Advanced Building Information Modelling" (Lecture, 2 SWS) "Advanced Building Information Modelling" (Seminar, 2 SWS)

Title	Advanced Modelling – Calculation	
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
	Project Work	60
	Self-study	45
	Exam preparation	30
Language of instruction	English	
Module coordinator(s)	Prof. Dr. rer. nat. habil. Klaus Gürlebeck – Chair of applied Mathematics Dr. rer. nat. Dmitrii Legatiuk – 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	Calculus at Bachelor level, ordinary differential equations	
Required examination (including partial exams if applicable)	Type	Project report, oral exam
	Requirements for exam registration	Project work successfully conducted during the semester
	Language	English
	Duration / Scope	30 min
	Weighting	Project Report (30 %) Oral exam (70%)
Target qualifications	After the course the students will be able to analyse models of mathematical physics appearing in engineering. The students can create a mathematical model, consisting in partial differential equations or boundary integral equations, for a given physical phenomenon and discuss qualitative and quantitative properties of the solutions. Specifically, the students will be able to model correctly inhomogeneous material properties, transmission conditions and coupled problems, and recognise the need for parameter identification. By help of computer algebra systems the students will be able to justify the quality of a chosen numerical method and to calibrate its parameters, if necessary.	
Content	Modelling in engineering; Mathematical models – partial differential equations and integral equations; Correct modelling of initial conditions, boundary conditions; Inhomogeneous media, Modelling of coupling and transmission conditions; Numerical methods; Individual project: Solution of an initial boundary value problem with Maple and/or Matlab	
Teaching and learning forms/Didactic concept	The topics will be presented in a lecture, deepened by exercises. In the second part of the semester the students work on individual projects. The results of these projects will be discussed in form of short presentations.	

Literature and special information	Will be announced in the lecture
Courses with SWS / ECTS	This module is comprised of: "Advanced Modeling" (Lecture, 2 SWS) "Advanced Modeling" (Exercise, 2 SWS)

Title	Collaborative Data Management	
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 coordinator(s)	Prof. Dr.-Ing. Koch, Christian – 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	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge of IT, Internet and programming	
Required examination (including partial exams if applicable)	Type	Short group report, group presentation, written exam
	Requirements for exam registration	Short group report, group presentation
	Language	English
	Duration / Scope	2 hrs exam
	Weighting	exam 70%, report 20%, presentation 10%
Target qualifications	This module provides student with a basic understanding of collaboration concepts and their implementation in a computer-based design environment. Students will learn how to decide on and how to use different technologies, such as document management systems, product data management systems, internet based project platforms and product model servers. Also the students acquire team working and presentation skills.	
Content	Computer-Supported Cooperative Work (CSCW) Distributed processing and management of product model data (Common Data Environments) Document management systems (DMS) Product data management systems (PDM) Internet based project platforms Product model servers	
Teaching and learning forms/ Didactic concept	Lectures; Seminars/tutorials in computer pool, group project, student presentations. Lectures provide the theoretical foundations that are applied to practical computer exercises and comprehensive student group projects.	
Literature and special information	Wilson, P. (1991), Computer Supported Cooperative Work: An introduction, Springer. Jorij, A. (2014), Product Information Management: Theory and Practice, Springer. Erl, T., Mahmood, Z., Puttini, R. (2013), Cloud Computing: Concepts, Technology and Architecture. Prentice Hall.	

Courses with SWS / ECTS	This module is comprised of: "Collaborative Data Management" (Lecture, 2 SWS) "Collaborative Data Management" (Seminar, 2 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 coordinator(s)	Prof. Dr.-Ing. Carsten Könke Professor for Structural Analysis and Component Strength	
Usability / Type of module	Compulsory elective module in the subject area "Modelling" for M.Sc. Digital Engineering Elective module for M.Sc. Natural Risks and Hazards in Structural 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 test
	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 min
	Weighting	
Target qualifications	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 difference 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	Modelling in the development process	
Semester (optional)		
Frequency	Every semester	
Interval and duration	Block seminar for 2 x 2 days	
ECTS / credit points	3 ECTS / 2 SWS	
Workload	In-class study / online-study	23
	Self-study	52
	Exam preparation	15
Language of instruction	English	
Module coordinator(s)	Prof. Dr.-Ing. habil. Könke, Carsten – Chair of Structural Analysis and Component Strength Dr.-Ing. Guist, Christian – BMW Group (external lecturer)	
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 mechanics	
Required examination (including partial exams if applicable)	Type	Oral or written exam (depending on the number of participants)
	Requirements for exam registration	
	Language	English
	Duration / Scope	1 h
	Weighting	
Target qualifications	The students will be familiar with a procedure for the solution of tasks from engineering practice with the help of models of the technical mechanics. This development and planning process serves as a guideline for modelling. The students will be trained to use modern CAD software (CATIA) and FEM Code (Abaqus, including pre- and post-processing).	
Content	In the modelling process, several development stages with increasing level of detail are used. According to these levels the appropriate models should be chosen: - Descriptive models - Schematic models - Qualitative models - Quantitative models Several criteria for model selection and a variety of tools for modeling are demonstrated.	
Teaching and learning forms/ Didactic concept	Lectures, exercises in computer pool, self-study	
Literature and special information	VDI 2220, VDI 2221, VDI 2223, VDI 3830 Koller, R.: „Konstruktionslehre für den Maschinenbau" Springer Verlag	

	Kochendörfer, B.; Liebchen, J.; ….: „Bau-Projekt-Management", Springer Verlag Bielefeld, B.: „Entwerfen Entwurfsidee", Birkhäuser Verlag Frey, H.: „Bautechnik" Verlag Europa-Lehrmittel Hibbeler, R.C.: „Technische Mechanik 1-3", Pearson Studium Gross, D.; Hauger, W.; …: „Technische Mechanik 1-3", Springer Verlag
Courses with SWS / ECTS	This module is comprised of: Modelling in the development process "Modeling in the Development Process" (Block seminar, 2 SWS)

Title	Introduction to Optimization / Optimization in Applications	
Semester (optional)	1 + 2 or 3 + 4	
Frequency	Once a year in the winter semester and Once a year in the summer semester	
Interval and duration	Weekly for 2 semesters	
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 coordinator(s)	Prof. Dr. rer. nat. Tom Lahmer - Juniorprofessorship Optimization and Stochastics	
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 (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 qualifications	The students will have a fair overview about typical optimization problems. After the course, Students can easily detect potential of improvements in technical, economic or social systems. The students have the ability to formulate the optimization problems in mathematical terms on their own and to classify the resulting problem. Depending on this classification, students have good training in quickly 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 Calibration 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 R. E. Burkard, U. Zimmermann - Einführung in die mathematische Optimierung L. Harzheim - Strukturoptimierung R. Kelley - Iterative Methods for Nonlinear Optimization
Courses with SWS / ECTS	This module is comprised of: "Introduction to Optimization", (Lecture, 2 SWS) "Optimization in Applications", (Lecture, 2 SWS)

IV. Subject Area “Simulation and Validation"

An introduction to the simulation of processes and structures is given in the subject area “Simulation and Validation". Special attention is given here to the treatment of stochastic input and output data, non-linear behavior and the use of efficient simulation methods. The validation of models is based on experimental data. For this purpose, methods of statistical design of experiments, as well as measurement methods, subsequent signal processing and methods for system and parameter identification are presented.

Module Title	**Module Coordinator**	**ECTS / SWS**	**Semester**
Design and Interpretation of Experiments / Signal Processing	M. Kraus /T. Lahmer	6 ECTS / 6 SWS	WS
Extended Finite Elements and Mesh Free Methods	T. Rabczuk	6 ECTS / 4 SWS	SS
Linear FEM	T. Rabczuk	6 ECTS / 4 SWS	WS
Modelling of Steel Structures and Numerical Simulation	M. Kraus	6 ECTS / 4 SWS	SS
Nonlinear FEM	T. Rabczuk	6 ECTS / 4 SWS	WS
Process modelling and simulation in logistics and construction	Bargstädt	6 ECTS	WS
Simulation Methods in Engineering	Koch	6 ECTS / 4 SWS	WS
Stochastic Simulation Techniques and Structural Reliability	T. Lahmer	6 ECTS / 4SWS	SS
Structural Health Monitoring	Smarsly	6 ECTS / 4 SWS	WS
System and Parameter Identification	V. Zabel	6 ECTS / 4 SWS	SS

<table>
<tr><td>Title</td><td colspan="2">Design And Interpretation of Experiments</td></tr>
<tr><td>Semester (optional)</td><td colspan="2">1 or 3</td></tr>
<tr><td>Frequency</td><td colspan="2">Once a year in the winter semester</td></tr>
<tr><td>Interval and duration</td><td colspan="2">Weekly for 1 semester</td></tr>
<tr><td>ECTS / credit points</td><td colspan="2">6 ECTS / 6 SWS</td></tr>
<tr><td rowspan="3">Workload</td><td>In-class study / online-study</td><td>56</td></tr>
<tr><td>Self-study</td><td>94</td></tr>
<tr><td>Exam preparation</td><td>30</td></tr>
<tr><td>Language of instruction</td><td colspan="2">English</td></tr>
<tr><td>Module coordinator(s)</td><td colspan="2">Prof. Dr. rer. nat. Tom Lahmer - Juniorprofessorship Optimization and Stochastics
Prof. Dr.-Ing. Kraus, Matthias – Chair of Steel and Hybrid Structures</td></tr>
<tr><td>Usability / Type of module</td><td colspan="2">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</td></tr>
<tr><td>Formal requirements for participation</td><td colspan="2"></td></tr>
<tr><td>Recommended requirements for participation</td><td colspan="2">Good knowledge in Applied Mathematics</td></tr>
<tr><td rowspan="5">Required examination (including partial exams if applicable)</td><td>Type</td><td>1 Written exam / 120 min / WiSe + SuSe including „Experiments in Structural Engineering"and „Signal Processing, Design of Experiments and System Identification"</td></tr>
<tr><td>Requirements for exam registration</td><td>Submission of Solutions of Computer Classes</td></tr>
<tr><td>Language</td><td>English</td></tr>
<tr><td>Duration / Scope</td><td>3 hours</td></tr>
<tr><td>Weighting</td><td>Project Report (33 %)
Written exam (67 %)</td></tr>
<tr><td>Target qualifications</td><td colspan="2">Students will be familiar with following: Design and setup as well as evaluation and interpretation of experimental testing in structural engineering. Provision of techniques linking experimental and mathematical / numerical modeling. Parallel assessment of steps being part of any verification and validation procedure. Discussion 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.</td></tr>
<tr><td>Content</td><td colspan="2">The course gives an overview on experiments and their evaluation regarding different 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, Fou-</td></tr>
</table>

	rier 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: "Design Of experiments" (Lecture, 2 SWS, Lahmer) "Design of Experimentes" (Computer Classes, 1 SWS, Lahmer) "Experiments in Structural Engineering" (Lecture, 2 SWS,Kraus)

Title	Extended finite elements and mesh free methods	
Semester (optional)	2 or 4	
Frequency	Once a year in the summer semester, at least 30 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 coordinator(s)	Prof. Dr.-Ing. Timon Rabczuk – Chair of computational mechanics	
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	Linear FEM	
Recommended require-ments for participation	Introduction to Tensoralgebra Nonlinear continuum mechanics Nonlinear FEM	
Required examination (in-cluding partial exams if applicable)	Type	Written or oral test depending on the number of partici-pants
	Requirements for exam registration	
	Language	English (SuSe)
	Duration / Scope	150 min. (written) or 30 min. (oral)
	Weighting	Written/Oral test (100 %)
Target qualifications	Students know about extended finite element and mesh free methods and their application and know how to implement XFEM and mesh free methods in computer code.	
Content	Meshfree Methods: Completeness, consistency, continuity, conservation, stability and convergence, kernel functions, specific meshfree approximations: SPH, corrected SPH versions, RKPM, EFG, LME, application to linear elastostatics, spatial integra-tion, essential boundary conditions, coupling to finite elements, Kinematics of strong and weak discontinuities, strong discontinuities in meshfree methods: visibility method, diffraction and transparency method, intrinsic and extrinsic enrichment, (if needed a short overview of LEFM), XFEM: Level sets, choice of enrichment functions for specific problems (material interfaces, cracks and shear bands), 'standard' XFEM: Integration, geometric and topological enrichment, blending elements, conditioning and implementation, application to LEFM, extension to linear elasto-dynamics, Hansbo-Hansbo XFEM and the phantom node method for fracture, specific applica-tions: complex moving boundary problems (crack branching, crack coalescence, to-pology optimization and inverse analysis, cohesive cracks); Short overview of alterna-tive methods for quasi-brittle and brittle fracture: remeshing techniques, embedded elements, cohesive elements, element deletion, smeared crack approaches, IGA (knot insertion) and XIGA, continuous methods for fracture: Phase field models, nonlocal and gradient models, viscous regularisation	

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
Courses with SWS / ECTS	This module is comprised of: "XFEM and meshfree methods" (Lecture, 2 SWS) "XFEM and meshfree methods" (Seminar, 2 SWS)

Title	Linear FEM	
Semester (optional)	1 or 3	
Frequency	Once a year in the summer semester, at least 10 participants	
Interval and duration	Weekly for 1 of 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 coordinator(s)	Prof. Dr.-Ing. Timon Rabczuk – Chair of computational mechanics	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Natural Hazards and Risks in Structural Engineering Compulsory elective module in subject area "simulation and validation" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation	Mechanics I Mechanics II	
Recommended requirements for participation	Introduction to Tensoralgebra	
Required examination (including partial exams if applicable)	Type	Written or oral test depending on the number of participants
	Requirements for exam registration	
	Language	English (WiSe)
	Duration / Scope	150 min. (written) or 30 min. (oral)
	Weighting	
Target qualifications	Students are able to implement simple FEM programs on their own. They know about the general workflow on a FEM simulation (from pre- to post-processing). Furthermore the students know about the advantages and disadvantages of different FE formulations and their areas of application.	
Content	Strong form, weak form and energy principles with application to linear elasticity, continuum elements (Q4 and T3), isoparametric concept, numerical integration, Hellinger Reissner and Hu Washizu principle, locking phenomena, mixed and hybrid continuum elements, Pian Sumihara element, reduced integration, plane beam elements (Euler Bernoulli and Timoshenko beam theory), plate elements (Mindlin-Reissner and Kirchhoff plate), concept to avoid locking phenomena in Mindlin Reissner plate elements: MITC4 and DSG	
Teaching and learning forms/ Didactic concept	The topics will be presented in a lecture, deepened in accompanying seminars.	
Literature and special information	Erikson, K., Estep, D., Hansbo, P., Johnson, C: Computational Differential Equations,Cambridge University Press 1996; Tang, W.H. Probability Concepts in Engineering: Emphasis on Applications to Civil and Environmental Engineering," New York: Wiley(2006); Arora, J.S., "Introduction to Optimum Design," Amsterdam: Elsevier (2004);	

	Nocedal, J., Wright, S.J., "Numerical Optimization,"New York: Springer (1999). Ross, S.M., "A Course in Simulation," New York: Macmillan (1990); Skripte
Courses with SWS / ECTS	This module is comprised of: "Linear FEM" (Lecture, 2 SWS) "Linear FEM" (Seminar, 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 coordinator(s)	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 require-ments for participation	Mechanics	
Required examination (in-cluding partial exams if applicable)	Type	Written exam
	Requirements for exam registration	
	Language	English
	Duration / Scope	120 min.
	Weighting	Written exam (100 %)
Target qualifications	The students will be familiar with skills and expertise in the field of nonlinear struc-tural 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 struc-tures.	
Content	Design of steel structures using finite element methods; basics of the design; model-ling of structures and loads; nonlinear material behaviour, numerical analyses of steel-members and structures regarding geometric and physical nonlinearities; stabil-ity 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 practi-cal tasks in exercises including computer applications.	
Literature and special in-formation	Literature: Kindmann, R., Kraus, M.: Steel Structures – Design using FEM. Ernst & Sohn publish-ing, 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	Nonlinear FEM	
Semester (optional)	3	
Frequency	Once a year in the summer semester, at least 30 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 coordinator(s)	Prof. Dr.-Ing. Timon Rabczuk – Chair of computational mechanics	
Usability / Type of module	Compulsory 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		
Recommended requirements for participation	Linear FEM Introduction to Tensoralgebra	
Required examination (including partial exams if applicable)	Type	Written or oral test depending on the number of participants
	Requirements for exam registration	
	Language	English (WiSe), German (WiSe)
	Duration / Scope	150 min (written) or 30 min. (oral)
	Weighting	Written/oral test (100 %)
Target qualifications	Introduction to nonlinear continuum mechanics, geometric nonlinearities, linearisation & directional derivatives, buckling & snap through, solution for nonlinear equilibrium equation, Newton Raphson and modified Newton Raphson method, linear search, path following techniques and arc length control, determination of critical points, geometrical nonlinear Q4 element, introduction to hyper elasticity and plasticity theory, consistent linearisation, 1D truss element for isotropic hardening.	
Content	Main focuses: Introduction to nonlinear continuum mechanics; geometric nonlinearities; material nonlinearities; linearization of nonlinear problems in elastic statics analyses; FE formulations for geometric nonlinear problems and their solution (including: Newton-Raphson, line-search and arc-length method); detection and handling of bifurcation points; contact.	
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	
Courses with SWS / ECTS	This module is comprised of: "Nonlinear FEM" (Lecture, 2 SWS) "Nonlinear FEM" (Seminar, 2 SWS)	

Title	Process modelling and simulation in logistics and construction	
Semester (optional)	3 (preferably), 1	
Frequency	Once a year in winter semester; minimum 5 students	
Interval and duration	Weekly over 1 semester	
ECTS / credit points	6 ECTS / 3 SWS	
Workload	In-class study / online-study	45 hrs
	Self-study	Self-study (including homework) 105 hrs
	Exam preparation	30 hrs
Language of instruction	English, bilingual	
Module coordinator(s)	Prof. Dr.-Ing. Hans-Joachim Bargstädt - Chair of Construction Engineering and Management	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Digital Engineering This module can be taken as an elective module.	
Formal requirements for participation		
Recommended requirements for participation	Basic knowledge of BIM concepts and software; experience in installing and exploring engineering freeware on a personal computer	
Required examination (including partial exams if applicable)	Type	Written or oral exam
	Requirements for exam registration (optional)	Homework assignment
	Language	English, bilingual
	Duration / Scope	2 hours
	Weighting (if applicable)	33 % written exam, 66 % partial exams/homework assignments
Target qualifications	Acquiring an overview about concepts of process design in construction. Being able to conceptualize and to design production and process chains for construction work. Students will achieve competency to create abstract models from real problems in construction operations. Ability to analyse performance rates and to perform optimization strategies. They acquire experience in group organisation and co-ordination, in interdisciplinary work, presentation techniques and leadership	
Content	The students learn about concepts of logistics and process engineering in the construction. They get acquainted with basic tools and software concepts for logistics and construction simulation. They learn to analyse construction tasks according to different process schemes and evaluations (prefabrication issues, logistics concepts, cyclogram techniques, lean production)	
Teaching and learning forms/ Didactic concept	Presentations by lecturer; group work and presentations of ongoing student's work. Guest lectures from industry	
Literature and special information	Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K.: BIM Handbook – A guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. 2nd edition, Wiley, 2011 Borrmann, A.; König, M.;, Koch, C.;, Beetz, J.: Building Information Modeling – Technologische Grundlagen und industrielle Praxis. Springer 2015	
Courses with SWS / ECTS	Not applicable	

Title	Simulation Methods in Engineering	
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 coordinator(s)	Prof. Dr.-Ing. Koch, Christian – 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 elective module for the degree programme M.Sc. Bauingenieurwesen	
Formal requirements for participation		
Recommended require-ments for participation	Basic knowledge of programming	
Required examination (in-cluding partial exams if applicable)	Type	Short group report, group presentation, written exam
	Requirements for exam registration	Short group report, group presentation
	Language	English
	Duration / Scope	2 hrs exam
	Weighting	exam 70%, report 20%, presentation 10%
Target qualifications	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 current problems in the context of civil and environmental engineering (e.g. production logistics, pedestrian simulation, pollutant dispersion). Using object-oriented simula-tion software the students will analyze, model and simulate different engineering 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 presentations. Lectures provide theoretical foundations that are applied in practical computer exer-cises and a comprehensive student group project.	
Literature and special in-formation	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 Modeling 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	Stochastic Simulation Techniques and Structural Reliability	
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
	Project Work	60
	Self-study	45
	Exam preparation	60
Language of instruction	English	
Module coordinator(s)	Prof. Dr. rer. nat. Tom Lahmer - Juniorprofessorship 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 "Simulation and Validation" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended require-ments for participation	Basics in "Probability Theory" are recommended.	
Required examination (in-cluding partial exams if applicable)	Type	1 Project report 1 written or oral exam (depending on the number of par-ticipants)
	Requirements for exam registration	Submission of assignments
	Language	English
	Duration / Scope	90 min.
	Weighting	Project Report (30 %) Written or oral exam (70 %)
Target qualifications	Soils, rocks and materials like concrete are in the natural state among the most vari-able 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 com-puter classes students additionally train their skills in cooperating 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 and an intensive practical training (Blockkurs) on applications by Dr. Thomas Most (DYNARDO, Weimar)
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	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) "Stochastic Simulations with OptiSlang", (BlockCourse, 2 SWS)

Title	Structural Health Monitoring	
Semester (optional)	3	
Frequency	Once a year in the winter semester, optional	
Interval and duration	Weekly for 1 semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	45
	Project Work	60
	Self-study	45
	Exam preparation	30
Language of instruction	English	
Module coordinator(s)	Prof. Dr.-Ing. Smarsly, Kay - Chair of Computing in Civil Engineering	
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 "Simulation and Validation" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended requirements for participation	Object-oriented modeling and Java programming language	
Required examination (including partial exams if applicable)	Type	1 project report (written paper) 1 oral examination
	Requirements for exam registration	(i) Development of a wireless SHM system, (ii) participation in project work (including laboratory tests), (iii) written paper
	Language	English
	Duration / Scope	20 min. oral examination
	Weighting	-
Target qualifications	Students will become familiar with the principles and practices of structural health monitoring and smart structural systems; they will be able to design decentralized systems to be applied for continuous (remote) monitoring of civil infrastructure. In addition, the students will learn to design and to implement intelligent sensor systems using state-of-the-art data analysis techniques, modern software design concepts and embedded computing methodologies.	
Content	In this course, principles of structural health monitoring are taught, focusing on modern concepts of data acquisition, data storage, and data analysis. Also, fundamentals of intelligent sensors and embedded computing will be illuminated. Autonomous software and decentralized data processing are further crucial parts of the course. Furthermore, measuring principles, data acquisition systems, data management and data analysis algorithms are discussed. Besides the theoretical background, numerous practical examples are shown to demonstrate how structural health monitoring can advantageously be used for assessing the condition of structural systems and, in further steps, for lifetime prediction and life-cycle management of civil engineering structures or structural parts. In addition to the lectures, a project work is included in this course. In small groups, the students design structural health moni-	

	toring systems that integrate a number of "intelligent" sensors to be implemented by the students. The structural health monitoring systems will be mounted on real-world structures, such as bridges or towers, for validation purposes. The outcome of every group is to be documented in a paper. The written papers and oral examinations form the final grades. This course is held in English. Limited enrollment. Prerequisites for this course: Object-oriented modeling and Java programming language. Requirements for examination: (i) Development of a wireless SHM system, (ii) participation in the project work (including the laboratory test), (iii) written paper.
Teaching and learning forms/ Didactic concept	Lectures, exercises, computer work, work with programmable sensor nodes in the lab, group work
Literature and special information	Will be announced in class
Courses with SWS / ECTS	This module is comprised of: "Fundamentals of structural health monitoring and intelligent structural systems" (Lecture, 2 SWS) "Fundamentals of structural health monitoring and intelligent structural systems" (Exercise, 2 SWS)

Title	System and Parameter Identification	
Semester (optional)	2 or 4	
Frequency	Once a year in the summer semester	
Interval and duration	Weekly for 1 of semester	
ECTS / credit points	6 ECTS / 4 SWS	
Workload	In-class study / online-study	60
	Project Work	80
	Self-study	40
	Exam preparation	0
Language of instruction	English	
Module coordinator(s)	Dr.-Ing. 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	Project Report (35 %) Presentation / Project Work (65 %)
Target qualifications	The students obtain deepened knowledge in structural dynamic analysis, processing of measured data, numerical implementation of identification methods, dynamic test equipment and its handling. They obtain experience in creating, validating and updating of numerical models representing the dynamic behaviour of a structure utilizing state-of-the-art methods. Further, the students develop competences 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 analysis 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. The project work is organized in small groups of students who have to collaborate, which also enhances their social competence, especially in the field of team work and presentation techniques.	

Literature and special information	Recommended Literature: Van Overschee, P. & De Moor, B.: Subspace identification for linear systems - Theory, 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 "System and Parameter Identification" (integrated Lectures, 2 SWS) Assisted Lab/Field experiments and partly assisted Project Work (2 SWS).

V. Subject Area “Visualization and Data Science"

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 “Visualization and Data Science". 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 Coordinator**	**ECTS / SWS**	**Semester**
Image Analysis and Object Recognition	V. Rodehorst	6 ECTS / 4 SWS	SS
Introduction to Machine Learning	B. Stein	6 ECTS / 3 SWS	WS
Machine Learning for Software Engineering	N. Siegmund	6 ECTS / 3 SWS	SS
Photogrammetric Computer Vision	V. Rodehorst	6 ECTS / 3 SWS	WS
Search Algorithms	B. Stein	6 ECTS / 3 SWS	WS
Software Product Line Engineering	N. Siegmund	6 ECTS / 3 SWS	SS
Visualization	B. Fröhlich	6 ECTS / 3 SWS	SS

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 coordinator(s)	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 require-ments for participation	None	
Required examination (in-cluding partial exams if applicable)	Type	Final written exam
	Requirements for exam registration	Successful completion of the lab classes
	Language	English
	Duration / Scope	90 min.
	Weighting	
Target qualifications	The course introduces advanced concepts of image processing, image analysis and object recognition. The goal is to understand the principles, methods and applications of computer vi-sion from image processing to image understanding. Students should learn the following topics: 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 Students should be able to apply the above topics for solving computer vision prob-lems. 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 engineering. 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 Image regions Machine learning
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 45-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	Course material: www.uni-weimar.de/en/media/chairs/computer-vision/teaching/image-analysis-and-object-recognition/ Literature: B. Jähne: Digital image processing, Springer, 2005. R.C. Gonzalez and R.E. Woods: Digital image processing, Prentice Hall, 2008. R. Szeliski: Computer vision: algorithms and applications, Springer, 2010. 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.
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) and a final small project

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 coordinator(s)	Prof. Dr. Benno Stein - Web Technology and 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		
Required examination (including partial exams if applicable)	Type	Final written exam.
	Requirements for exam registration	Active participation in lab classes
	Language	English
	Duration / Scope	1.5h
	Weighting	Not applicable
Target qualifications	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 foundations of supervised learning also an introduction to unsupervised learning is given. Students should understand the following concepts and theories: classifier design hypothesis space model bias impurity functions statistical learning neural networks cluster analysis 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 cluster merging principles in order to tackle learning and mining problems and their application to Digital Media. 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 examples Linear regression Concept learning Decision trees Bayesian learning Neural Networks Cluster analysis
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: http://www.uni-weimar.de/en/media/chairs/webis/teaching/lecturenotes/#machine-learning Tools: Weka, 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* P.N. Tan, M. Steinbach, V. Kumar. *Introduction to Data Mining*
Courses with SWS / ECTS	This module is comprised of: "Introduction to Machine learning" (Lecture, 2 SWS) "Introduction to Machine Learning" (Exercise, 1 SWS)

Title	Machine Learning for Software Engineering	
Semester (optional)	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	116
	Exam preparation	30
Language of instruction	English	
Module coordinator(s)	Prof. Dr.-Ing. Siegmund, Norbert - Intelligent Software Systems	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media Compulsory elective module for the degree programme M.Sc. Human Computer Interaction Compulsory elective module in the subject area "Visualization and Data Science" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended require-ments for participation	Lecture on Introduction to Machine Learning and Software Engineering	
Required examination (in-cluding partial exams if applicable)	Type	Project report and written or oral examination depending on the number of participants.
	Requirements for exam registration	Participation requires the successful completion of the course labs.
	Language	English
	Duration / Scope	25min oral / 60-90min written
	Weighting	Partial exam based on a given project will make 20% of the final grade
Target qualifications	Machine Learning for Software Engineering is about learning and optimizing complex tasks that are computationally intractable for exact methods. The goal of this course is to understand the principles of meta-heuristics in optimization as well as key con-cepts of learning based on neural nets. Students should understand the following techniques and theories: Problem space exploration and search-based optimization Meta-heuristics for optimization Relationship between biological learning and optimization with algorithms Neural nets and deep learning Students should be able to apply the above theories for solving concrete learning and optimization problems. Furthermore, they should appreciate the limits and con-straints of the individual methods above. Students should be able formalize and generalize their own solutions using the above concepts and implement them in a specified language (preferable in Python).	

	Students should develop an understanding of the current state of research in optimization and learning. With appropriate supervision, students should be able to tackle new research problems, especially in the area of search-based software engineering.
Content	Students should master concepts and approaches such as Single-State Meta-Heuristics Hill Climbing Simulated annealing Multi-State Meta-Heuristics Swarm optimization Ant colonization Evolutionary algorithms Constraint Satisfaction Problem Dimensionality Reduction Neural nets Deep learning In order to tackle problems learning and optimizing huge problems, which are inherent to Digital Media. They should also be able to implement the algorithms and techniques in Python and be able to understand a proposed problem, to compare different approaches and techniques regarding applicability and accuracy, to make well-informed decisions about the preferred solution and, if necessary, to find their own solutions.
Teaching and learning forms/ Didactic concept	Interaction and explorative teaching concept, including buzz groups, hands-on programming in live Python sessions. We will use several forms of media: presentations, white-board, Jupyter Notebooks for live programming, etc. We will give tutorials in the exercises to cover basic Python topics as well as dive into the most relevant Deep Learning libraries: Keras and TensorFlow.
Literature and special information	Handbook of Metaheuristics, Fred W. Glover, Gary A. Kochenberger, Springer Science & Business Media, 2006. Machine Learning, Tom Mitchell, McGraw-Hill Education, 1997. Essentials of Metaheuristics, Sean Luke, 2013. A Field Guide to Genetic Programming, Riccardo Poli, William B. Langdon, Nicholas Freitag McPhee, Lulu Pr, 2008. Make Your Own Neural Network, Rashid, Tariq, CreateSpace Independent Publishing Platform, 2016. http://neuralnetworksanddeeplearning.com/index.html (online book)
Courses with SWS / ECTS	"Machine Learning for Software Engineering" (Lecture, 2 SWS) "Machine Learning for Software Engineering" (Exercises, 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 coordinator(s)	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	None	
Required examination (including partial exams if applicable)	Type	Final written Exam
	Requirements for exam registration	Successful completion of the lab classes
	Language	English
	Duration / Scope	90 minutes
	Weighting	
Target qualifications	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) Modeling and interpretation of a camera Optical imaging with lenses Epipolar geometry and multi-view tensors Global bundle adjustment Robust parameter estimation 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 formalize and generalize 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 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 and one 45-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	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. Y. Ma, S. Soatto, J. Kosecka and S. Sastry: An Invitation to 3D-Vision – From Images to Geometric Models, 2. Edition, Springer, 2005. R. Szeliski: Computer vision: algorithms and applications, Springer, 2010.
Courses with SWS / ECTS	The module consists of the following courses: "Photogrammetric Computer Vision" (Lecture, 2 SWS) "Photogrammetric Computer Vision" (Lab, 1 SWS) and a final small project

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 coordinator(s)	Prof. Dr. Benno Stein - Web Technology and 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	B.Sc.	
Recommended require-ments for participation	Algorithms and Data Structures.	
Required examination (in-cluding partial exams if applicable)	Type	Written exam.
	Requirements for exam registration	Active participation in lab classes.
	Language	English
	Duration / Scope	1.5h
	Weighting	Not applicable
Target qualifications	The course will introduce search algorithms as a means to solve combinatorial prob-lems such as constraint satisfaction and optimization problems. Tackling such prob-lems 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 repre-sentation 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 un-derstand the principle of admissible search and to prove basic properties of the search algorithms (completeness, soundness, admissibility).	

	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: http://www.uni-weimar.de/en/media/chairs/webis/teaching/lecturenotes/#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	Software Product Line Engineering	
Semester (optional)	2/4	
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	116
	Exam preparation	30
Language of instruction	English	
Module coordinator(s)	Prof. Dr.-Ing. Siegmund, Norbert - Intelligent Software Systems	
Usability / Type of module	Compulsory elective module for the degree programme M.Sc. Computer Science for Digital Media Compulsory elective module for the degree programme M.Sc. Human Computer Interaction Compulsory elective module in the subject area "Visualization and Data Science" for the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended require-ments for participation	Lecture: Software Engineering	
Required examination (in-cluding partial exams if applicable)	Type	Written or oral examination.
	Requirements for exam registration	Participation requires the successful completion of the course labs.
	Language	English
	Duration / Scope	25min oral; 60-90min written
	Weighting	No partial examinations
Target qualifications	Software product lines and configurable software systems are the main driving factor for mass customization, tailor-made products, and product diversity while keeping a maintainable code base and saving development time. The lecture will teach about central elements of product line modelling and development. Students should understand the following techniques and theories: Configuration management and variability modeling Classic and modern programming techniques, such as preprocessors, version control systems, components, frameworks, aspect-oriented programming, and feature-oriented programming Feature interactions and virtual separation of concerns Students should be able to apply the above theories and concepts to judge points in favour and against a certain technique depending on the application scenario at hand. Hence, the students will be able to decide which techniques, tools, and meth-ods to use. Students should develop an understanding of the current state of research in soft-ware product lines. With appropriate supervision, students should be able to tackle new research problems, especially in the area of product line development and op-	

	timization.
Content	Students should master concepts and approaches such as The exponential complexity of variability spaces Modelling and implementation of program families, product lines, and domain specific generators Basic concepts of software engineering (e.g., cohesion, scattering, tangling, information hiding) Classic and modern concepts, such as preprocessors, plug-in systems, feature modules, collaborations, aspects, and roles Critical discussion about pros and cons of the above techniques and concepts Feature interactions, non-functional properties, product line analysis Students will implement these concepts in Java.
Teaching and learning forms/ Didactic concept	Interactive lectures with discussions and practical work. Exercises will exactly follow the lectures in implementing the concepts taught concepts so that theory and practice come hand in hand. As teaching concepts, we will use topic maps, buzz groups, randomized team competitions, and others.
Literature and special information	Script; Sven Apel, Don S. Batory, Christian Kästner, Gunter Saake: Feature-Oriented Software Product Lines - Concepts and Implementation. Springer 2013; Krysztof Czarnecki, Ulrich Eisenecker : Generative Programming. Methods, Tools and Applications. Addison Wesley 2000
Courses with SWS / ECTS	"Software Product Line Engineering" (Lecture, 2 SWS) "Software Product Line Engineering" (Exercises, 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	40
Language of instruction	English	
Module coordinator(s)	Prof. Dr. Bernd Fröhlich - Virtual Reality and Visualization Research Group	
Usability / Type of module	Compulsory Elective module in the subject area "Visualization and Data Science" of the degree programme M.Sc. Digital Engineering	
Formal requirements for participation		
Recommended require-ments for participation	Basic programming knowledge at bachelor level from a suitable previous degree	
Required examination (in-cluding 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 qualifications	The students will have an overview of the fields information visualization and scien-tific visualization. They know a 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-dimensional and hierarchical data, graphs, time series, cartographic and categorical 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 frame-works.	
Teaching and learning forms/ Didactic concept	Lectures are combined with project-oriented and lab work based on concrete prob-lems (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 coursework.
Literature and special information	Literature: Information Visualization (3rd Edition) by Robert Spence.
Courses with SWS / ECTS	This module is comprised of: "Visualization" (Lecture, 2 SWS) "Visualization" (Exercise, 1 SWS)