Degree Program Documentation
Master’s Program
Computational Mechanics

Part A
TUM School of Engineering and Design
Technical University of Munich

General Information:

- Administrative responsibility: TUM School of Engineering and Design
  Professional Profile Civil and Environmental Engineering
- Name of degree program: Computational Mechanics
- Degree: Master of Science (M. Sc.)
- Standard duration of study and credits:
  4 semesters of enrollment and 120 credit points (CP)
- Form of study: full time
- Admission: Aptitude assessment (EV – Master's)
- Start: Winter semester (WiSe) 2000/2001
- Language(s) of Instruction: English
- Main Location: Munich
- Tuition fees for students from non-EEA countries:
  Tuition fee category 2 (6.000 € per semester)
- Academic administrator (program design):
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1 Degree Program Objectives

1.1 Purpose

Computational mechanics (COME) is a constantly growing field with impact on both science and industry in all areas of engineering. It is concerned with solving mechanical problems based on numerical approximation methods, involving the transfer of physical configurations into adequate models and related mathematical equations which are numerically solved in in space and time. Nowadays, related skills are indispensable in civil and mechanical engineering, for the design of automobiles and spacecrafts, for developments in biomechanics and micro-electro-mechanical systems. Virtually all technical disciplines make use of the fast progress in this area.

Computational mechanics brings together highly sophisticated methods of theoretical, applied and structural mechanics, as well as computer science, software engineering and applied mathematics. Being familiar with the scientific background of this fascinating field opens the door to employment in all fields of engineering.

The rapid development of computers and the therewith connected technologies make the practical computation of scientific phenomena possible which haven’t been ascertainable yet. Nowadays, engineers that are targeting a professional career in COME are demanded to have a consolidate knowledge in mechanics, modelling, mathematics and computer sciences. Thus, a strong background in Computational Mechanics opens a successful career in many fields of engineering. The interdisciplinary education conveys the ability to find innovative, creative and efficient solutions for the individual case and in consideration of the given time frame and budget. Computational modeling and simulation of physical processes as supplement to experimental methods are about to become an everyday tool, available at relatively low cost. Thus, the methods used in the field of Computational Mechanics are the future-oriented techniques modern engineering requires.

Typical applications can be found, e.g., in

- Civil Engineering: new materials, nonlinear and dynamical structural behavior, interaction between building and environment, structural optimization and form finding, estimation of fatigue strength, transient behavior, flow-simulations, coupling of CAD and computing, information and internet technology.
- Mechanical and Automotive Engineering: 3-D-structural analysis, nonlinear dynamics, optimization, multibody dynamics, crash, and vibroacoustics.
- Aerospace Engineering: fluid-structure-interaction, structural optimization, supersonic flight, high temperature exposure in the aerospace, active dampers, stratosphere balloons.
- Biomechanics and Medical Engineering: material models (e.g. bones, tissues), prostheses, implants, artificial blood vessels.

Therefore, the degree program aims at training engineers at the border between mechanical engineering, civil engineering, informatics and mathematics. The students shall be qualified as specialists in numerical analysis and simulation of complex engineering problems. For the solution of these problems, they can build a bridge between classical engineering disciplines, mathematics, informatics and software development. To achieve this goal, the degree program shall enable the students to develop own ideas and push the boundaries of their profession, and is thus research oriented.

1.2 Strategic Significance

In its goals and values[1], the Technical University of Munich (TUM) places people, nature, and society at the center of a sustainable innovation progress. In the pursuit of responsible and socially acceptable innovations, TUM expands the concept of engineering and opens it up to the humanities and tailors programs for competencies integrating various research fields from different engineering disciplines and natural sciences. The TUM matrix organization of schools and interdisciplinary research centers reflects this concept. In the TUM School of Engineering and Design additional knowledge and methods are generated through the integration of different disciplines and cooperations across different sites. The focus of its activities is on the analysis, simulation, and development in the fields of technology, mobility, energy, nature, materials and the built environment - experts and new talents tackle complex challenges with a sense of responsibility for people and the planet Earth. Solutions for a sustainable future are designed in innovation partnerships.[2]

The degree programs at TUM are assigned to Professional Profiles (PPs). These profiles organize the degree programs and their competence and qualification profiles not only along the "traditional" engineering disciplines. Based on current and future challenges, they transfer research content with cross-sectional competencies across subject and school boundaries into teaching. The degree programs of the School of Engineering and Design are currently grouped into the following nine PPs:

- Aerospace
- Architecture and Design
- Civil Engineering
- Environmental Engineering
- Geodesy
- Geo Engineering
- Interdisciplinary Engineering
- Mechanical Engineering
- Mobility

The degree program Computational Mechanics is assigned to the PP Civil Engineering. The PP Civil Engineering furthermore includes the degree programs

[1] https://www.tum.de/en/about-tum/goals-and-values/mission-statement
[2] https://www.ed.tum.de/en/ed/about/

- B. Sc. Civil Engineering,
- M. Sc. Civil Engineering,
- M. Sc. Information Technologies for the Built Environment,
- M. Sc. Resource Efficient and Sustainable Building,

The degree program Computational Mechanics is positioned at the interface between various engineering disciplines and offers interested engineering graduates the opportunity to specialize in the interface subject of computer-aided mechanics. Merging the various engineering disciplines creates an interdisciplinary atmosphere which is of huge benefit to the students. Likewise, the shared element of computer-aided mechanics has a high appeal for international applicants. The inter-departmental element is very apparent in the curriculum. Anchoring the degree program in the professional profile of Civil Engineering, a department which focuses on transferring complex physical processes to models in many areas, allows students from other disciplines a general overview of the fundamental engineering processes, in particular the design of unique models that do not allow the preliminary production of prototypes or testing. In its particular focus on the implementation of a broad spectrum of solution strategies to various complex mechanical phenomena, this degree program is unique and differs from other Master's degree programs of the professional profile (e.g. "Transportation Systems" or "Resource Efficient and Sustainable Building"). In some parts there are overlaps with the Master's program "Civil Engineering" offered at the TUM School of Engineering and Design. Nevertheless, the Master's degree program "Civil Engineering" focuses on a more general engineering perspective, while the COME program allows a very specific approach to computer-aided mechanics. Also, through its international orientation and accessibility for students with different backgrounds (comp. Section 3), the program creates a beneficial atmosphere for interdisciplinary exchange in between students but also with respect to the participating chairs and the school itself.

The COME program is embedded in the focus area "Modeling-Simulation-Processes". Within this focus area, it serves as a specially tailored interdisciplinary program that combines the school's expertise in the fields of numerical modeling and computer implementation. The degree program contributes to the development and transfer of knowledge and skills in this field as well as to the development and transfer of methods, strategies and good practice examples for computational mechanics.

2 Qualification Profile

After successful finishing his/her studies, a Master of Science of Computational Mechanics graduate has developed a portfolio of knowledge skills and competencies in the field of numerical simulation, modelling of engineering problems for a consequent numerical simulation and a profound understanding of mechanical problems. Overall, graduates are specialized in simulating structures or components thereof as well as fluids. They are able to translate complex physical systems into mechanical models and to predict the system behavior using elaborate numerical analysis tools.

For Master's programs, the following four areas of competence have been defined: Knowledge and understanding (1), Usage, application and generation of knowledge (2), Communication and cooperation (3), and Scientific self-understanding/ professionalism (4).[3]

2.1 Knowledge and Understanding

Based on the competencies achieved during their individual Bachelor's program, graduates from the Master's Program in Computational Mechanics gain a deeper understanding during the Master's program. As a part of that, they have the knowledge and a solid understanding of how to analyse structural-mechanical or fluid-mechanical engineering problems and how to transfer them into appropriate numerical models. They are able to interpret the particular terminology of their field of study and define and explain the underlying concepts. COME graduates are able to employ their knowledge and understanding in research or practical applications. Furthermore, they are able to critically reflect upon new research developments in the field of Computational Mechanics.

Besides, the graduates are able to evaluate the model assumptions linked with limitations of models, explain artefacts created during the modelling and evaluation process, give possible expansions of models for problems where the model assumptions might be violated and have detailed knowledge of numerical techniques to solve the engineering problems with the help of the developed models.

They derive ideas in engineering work as far as optimization of engineering products is concerned and are able to assess selected software tools. Therefore, they make scientifically founded decisions and can critically reflect on the consequences. The graduates are able to apply selected software tools and to get auto-didactically acquainted with new software products for numerical simulations.

COME graduates are able to apply complex principles in programming, including, e.g., parallel computing, and software development. They evaluate the underlying partial differential equations for various engineering problems, mainly from solid and fluid mechanics, know the assumptions for material description for a huge variety of different materials as well as those for the application of low and high frequency analysis.

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[3] The qualification profile meets the requirements of the Qualifications Framework for German Higher Education Qualifications ("Hochschulqualifikationsrahmen" – HQR) from 16th February 2017.

2.2 Usage, application and generation of knowledge

The starting points of the study program Computational Mechanics are in-depth understanding of the foundations of continuum mechanics and fluid mechanics on the one hand, and the numerical solution of therefrom resulting complex differential equations. Based on these competencies that go beyond the usual approaches of technical mechanics or technical fluid mechanics of a classical civil or mechanical engineer, the graduates of COME have a deeper knowledge of these topics and the ability to assess, optimize, and calculate system responses for concrete constructions and systems. This is largely independent of the specific application, may it be Civil, Aerospace, or Automotive Engineering. Based on their sound knowledge of numerical methods and the underlying model boundaries for materials as well as system behaviour, the students can universally assess simulation results with respect to numerical and mechanical artefacts. In particular, they are able to critically reflect upon the obtained computation results with respect to underlying assumptions regarding the materials, chosen mechanical formulations, as well as the numerical discretization and solution strategy. Thereby, the students gain a deep fundamental knowledge in the basics of solid and fluid mechanics as well as numerical analysis and its computer implementation. These competencies are especially important in practical applications in the industry to identify non-transparent artefacts in the numeric approximation and the modelling process that are usually not avoidable in the usage of black-box simulation software

In the field of scientific innovation, the students pose current questions in the field of computational mechanics, numerical static and dynamic analysis, and fluid mechanics and solve these through the application of appropriate research methods. They are finally able to critically reflect upon those ideas and communicate the approaches and results.

2.3 Communication and cooperation

After graduating from the Master’s Program in Computational Mechanics, graduates are able to give presentations in front of an international academic audience. They also have the knowledge of how to prepare these presentations concisely. COME graduates are able to work in an independent manner through their expertise to extract relevant problems by themselves. They have the expertise to discuss their scientific findings with international experts.

COME graduates have good social and communication skills, enabling them to work together in a cooperative way. Furthermore, they are sensitive to issues arising in cross-cultural and interdisciplinary work environments. The graduates act in a responsible way and are tolerant and open-minded with respect to their fellow human beings and co-workers.

They enhanced their communication skills in groups with both academics and non-academics from various disciplines in the Computational Sciences as well as Engineering sciences. The Graduates are able to identify the conflict potential in a collaborative process and can develop solutions if conflicts arise. They are able to build a bridge between both professional communities and are thus able to discuss feasible alternatives for solving interdisciplinary and subject-related problems.

2.4 Scientific self-understanding and professionalism

Graduates of the Master’s Program in Computational Mechanics at TUM are able to justify their own professional actions in the field of Computational Mechanics based on their solid knowledge in the fields of mechanical modelling and computer implementation and critically reflect upon the results of their work. Through their studies, they have developed a professional self-understanding based on the objectives and standards of professional action in academia and society. They assess their own abilities, know about the boundaries of their knowledge and make use of their freedoms of modelling and implementation choices independently. They are able to further develop them independently or under supervision. COME graduates recognize the limits of the applied theories and have learned to critically reflect their professional actions with regard to the predictability of these theories and methods. Thereby they always assess their own abilities and know how to develop their professional actions in the field of Computational Mechanics further.

Finally, graduates of the Master's program in Computational Mechanics can reflect on their impact on the environment and society. Especially rapidly developing techniques, e.g., generative artificial intelligence, require the graduates to not only be proficient in the technical details but also with the social and environmental consequences of these technologies. This will enable the graduates to put forward solutions and technical development that are aligned with sustainable development goals, while providing cutting edge solutions in research and industry. This is particularly relevant for the topics imposed by climate change, for which humanity will need to develop a multitude of solutions. Out of these, technical solutions are a cornerstone to which graduates in the field of Computational Mechanics can contribute.

3 Target Groups

3.1 Target Audience

The Master's program of Computational Mechanics focuses on national and international Bachelor's graduates in the fields of Civil or Mechanical Engineering who are especially interested in the link between the various fields of mechanics and engineering applications. It thus provides the possibility for students of civil engineering to obtain insights into other fields in engineering and to establish contact with other types of industries outside of civil engineering. On the other hand, it provides a link for students coming from mechanical engineering towards special topics in civil engineering, e.g. structural dynamics, hydromechanics. It thus can be considered as an interdisciplinary program bridging different engineering fields with the common basis of computational mechanics.

3.2 Prerequisites

The Master's program Computational Mechanics requires a strong background in engineering, structural and/or applied mechanics and good skills in mathematics and informatics. Therefore, the program is open to students of engineering Bachelor programs if these programs provide a comparable base in mathematics, mechanics and informatics as the TUM Bachelor programs in Civil or Mechanical Engineering. The selection of the students is done very carefully in the scope of an aptitude assessment of each application to reduce the number of dropouts. A GPA above 2,5 (converted according to the so-called Bavarian formula into the German grading system) gives an important benefit in the aptitude assessment, where a lower GPA will be more beneficial. Moreover, applicants need to prove their skills in the English language through submitting one of the following: Test of English as a Foreign Language" (TOEFL) with at least 88 points, the „International English Language Testing System" (IELTS) with at least 6.5 points, the „Cambridge Main Suite of English Examinations" or a certificate stating that the applicants have taken modules of at least 30 credits in their Bachelors that are taught in English. They need to explain their motivation for the studies in Computational Mechanics with the help of a short letter and need to provide at least one recommendation from one of their professors. Furthermore, a student's aptitude is proven through having gained competencies that are comparable to those taught in the Bachelor degree programs Civil Engineering and Mechanical Engineering at TUM. The details of the aptitude assessment are described in the study regulations. We specifically require the students to have a strong background in solid and fluid mechanics, mathematics and informatics. These are, inter alia, competencies in Technical Mechanics, dynamics, flow mechanics, linear algebra, analysis, differential equations and programming. The quality of the selection process is proven by the very low dropout rate of around 5% per year during the last years.

3.3 Target Numbers

The degree program Computational Mechanics is designed for approximately 30 students per intake. The limiting elements are on the one hand side infrastructure as far as computer rooms are concerned (currently 35 working places) and the individual support of the students. Nevertheless, the number of students increases with the increasing number of applications. Currently, approximately 35 students are enrolled, which sometimes, unfortunately, leads to crowded lecture rooms. There is an enormous interest in the degree program, which requires a competitive pre-selection out of more than 500 students, among which approximately 35 are enrolled in the program. Illustration 1 shows the evaluation of the number of applications, the admitted students, and the freshmen starting the program over time. In general, all numbers have grown, which emphasizes the growing popularity of the topic of the degree program. Due to the internet boom (esp. social media), information about this program gets spread faster around the world than in the beginning of the program. This fact attracts, together with the abolishment of study fees in Bavaria until the winter semester 2024/2025, more and more international applicants. Unfortunately, many of these additional applications cannot meet the challenging prerequisites of the program. Therefore, the number of applications has grown much faster than the number of additions and freshmen. Especially the number of applications of Indian, Iranian, Pakistani, Turkish, Chinese and German applicants grew in the last years.

Since the program's beginning in the winter semester 2000/2001 up to the winter semester 2024/2025, 745 students out of at least 56 different countries started the program. Based on the data starting from winter semester 2008/2009, the majority of the students come from Europe (44 %) and Asia (37 %). Additionally, 13 % of the students come from America, 4 % from Africa, and approximately 2 % of the students come from Oceania. Approx. 85 % of the students enrolled are international, thus 15 % of the students come from Germany. Since the establishment of the Bachelor-Master system at TUM, the number of German applicants has increased.

The most applications by far come from India. But also, Pakistan, Iran, Turkey and China provide a remarkable number of applications. Germany is on rank 6 regarding the number of applications.

Application numbers and matriculations have decreased in the winter semester 2024/2025 due to the introduction of study fees for international students. Since the introduction of the study fees has only occurred recently, it is too early for a solid analysis of the consequences for the Master's program. The situation is monitored, and measures will be taken if the above goals are not met in the future.

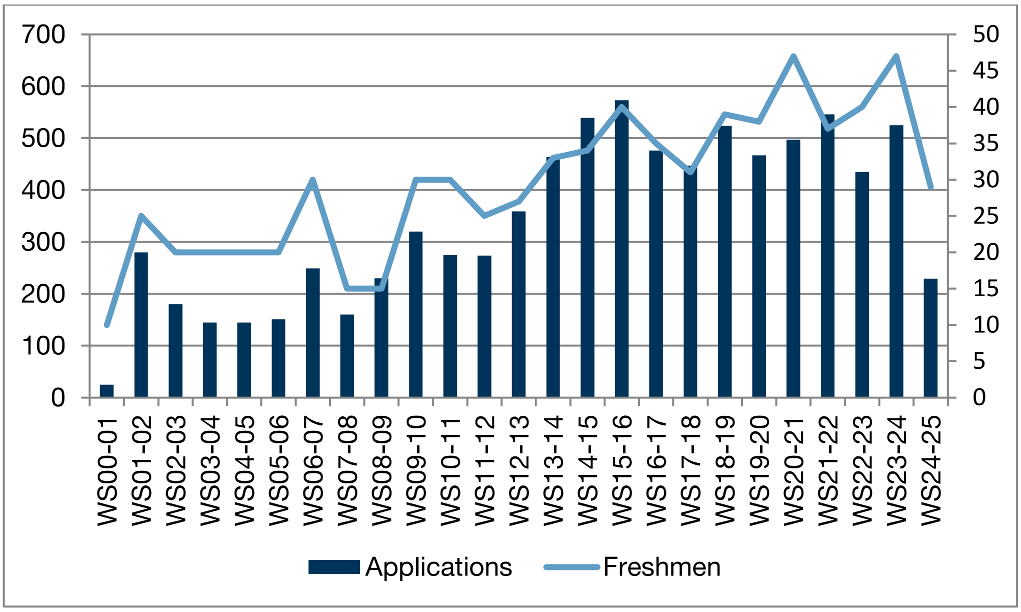

Illustration 1: Number of applications, admissions and freshmen. The number of applications (bars) links to the left axes, the number of freshmen (solid line) links to the right axes.

4 Demand Analysis

Graduates in Computational Mechanics should work as a new type of engineer on a borderline between various disciplines, such as mechanical and civil engineering, informatics and mathematics, in engineering companies focusing on structural dynamics, acoustics, fluid mechanics, vehicle engineering, aerospace, software development, or in the classical fields of civil engineering with a special focus on structural analysis. Therein, they are experts in numerical analysis and simulation of engineering problems with specific competencies in the simulation of structures and fluids and their fundamental understanding of modeling complex physical systems and can provide a link between different classical engineering disciplines and software development. With their qualifications (see Section 2), the expected employment possibilities are Civil and Mechanical Engineering companies as well as research institutions and software developers. Due to their research competencies in computational mechanics, they are also qualified for career paths in research institutions or universities focussing on computational mechanics.

In the extended quality management circles of 2022 and 2025, external experts that stem from different COME-relevant fields, such as civil or mechanical engineering and academia, stated that the course content of COME is very relevant for the German labour market. They also see a high need for COME graduates. Furthermore, there was only positive feedback by the employers in Germany regarding their experience with hiring COME graduates. Also, a search on www.stepstone.de (an online job portal) on 14 January 2025 delivers around 1,264 open positions regarding "Mechanical Computational Engineer".

The remainder of this analysis as well as the competitive analysis in section 5 is based on three surveys of in total 127 graduates of the program between 2002 and 2023. The surveys took place in 2012 (74 participants), 2018 (13 participants), 2020 (10 participants), and 2023 (30 participants). In the following, mean values of the first two surveys are presented. The third and fourth survey verify the findings of the first two surveys, but due to the low number of participants, we refrain from drawing detailed conclusions. Some questions haven't been asked in 2018 and 2020 as compared to 2012. None of the graduates had problems in finding a job on the labour market.

The surveys showed that the graduates find jobs in various companies from different sectors, such as Automotive and Aviation Industry, Civil Engineering, Simulation Engineering and Consulting, Mechanical and Plant Engineering and Software Development & Engineering. Another important part of the labour market which is relevant for COME alumni is research and development, both in the private sector and at many universities, where they often receive doctoral positions. Furthermore, many of the graduates start working in Germany after graduation. In the survey of 2023, around 70 % of the graduates indicated that they found a job in Germany while just around 30% found a workplace in Europe or overseas. More specifically, around 43% stayed in Munich or the surroundings after studying COME. This is a great success in consideration of the fact that approx. 73% of the students that participated in the surveys come from abroad (survey 2012: 80%; survey 2018: 54%; survey 2020: 60%; survey 2023: 70 %) and proves the high demand of the graduates at the German labour market. Besides, 43% (survey 2012: 46%; survey 2018: 16%; survey 2020: 20%; survey 2023: 55%) of the 127 graduates who participated in the surveys stated that they continued with doctoral studies after graduation, among them 20 graduates at TUM.

Many students have Mechanical or Civil Engineering and Applied/Computational Mechanics as academic background from their bachelor’s. Other backgrounds are Aerospace or Automotive Engineering as well as Mechatronics and Naval Architecture. This can be compared with the fields of engineering in which the students were employed after graduation. The surveys show that the program’s curriculum attracts applicants from different fields of engineering and allows the graduates to work in various fields of engineering. Whereas approx. 90% of the students have a background in the traditional fields of engineering such as civil, mechanical, aerospace engineering and applied mechanics, the graduates are employed in even more various fields like Simulation, Development Engineering or Multi Body Dynamics.

5 Competition Analysis

5.1 External Competition Analysis

In Germany, a continuously increasing number of international (English taught) Master's programs in the field of Computational Mechanics, Computational Engineering and Computational Sciences (www.hochschulkompass.de) exists. Apart from the Computational Mechanics program at Technical University of Munich, the following list gives a comprehensive overview over the various programs. The **University of Stuttgart** offers a program on Computational Mechanics of Materials and Structures and the **University Duisburg-Essen** offers a program on Computational Mechanics. Programs on Computational Engineering are offered at **Ruhr-Universität Bochum**, **Technical University Darmstadt**, **Friedrich-Alexander-University Erlangen-Nürnberg**, and **Technical University of Kaiserslautern**. The program Computational Engineering Science is offered at **RWTH Aachen**. The program Computational Science and Engineering is offered at **Technical University of Dresden**, **Technical University Bergakademie Freiberg** and **University Ulm**. The program Computational Sciences and Engineering is offered at **University of Rostock**, and the program Computational Sciences in Engineering is offered at **Technical University Braunschweig**. The **Bergische Universität Wuppertal** offers a program on Computational Simulation in Science. All of the above programs can be studied full-time.

Internationally, programs on Computational Mechanics are rarely taught. Most of the programs that are offered focus on Computational Science and Engineering, such as the program at **Massachusetts Institute of Technology**. Programs with a similar focus to COME at TUM are the Computational Mechanics program at **Sorbonne University** in Paris, which is in cooperation with **La Sapienza University** in Rome. Another joint degree is offered by **Swansea University**, **Stuttgart University**, **Polytechnic University of Barcelona**, **École Centrale de Nantes**, and **University of Padova**. Additionally, **Duke University** in the United States offers a Master's program on Computational Mechanics.

All the programs have in common that they have an interdisciplinary curriculum combining informatics and problems in science and engineering. However, contrary to most of the programs, the Master's program Computational Mechanics of TUM concentrates on a solid theoretical education in general mechanics, which is needed for solving problems in different fields of engineering. This element is shared with the degree programs offered at the universities in Stuttgart and Duisburg-Essen. Another difference to other programs is the link to civil engineering, which is very valuable as civil engineers have to deal with unique structures not permitting physical tests during their development. As already presented in Section 4, the program's curriculum attracts applicants from different fields of engineering and allows the graduates to work in various fields of engineering.

According to the first and second graduate survey referred to in section 4, the most important reasons for choosing the Master's program Computational Mechanics are the good reputation of TUM (46% of survey participants), the interest in the program's curriculum (39% of survey participants) and the uniqueness of the program (15% of survey participants). Furthermore, alumni of the program who are spread all over the world are excellent ambassadors for the Master's program Computational Mechanics and recommend it to their compatriots. Finally, 93% of the graduates in the 2023 poll indicated that they would study COME again, which we consider a satisfactorily large number.

5.2 Internal Competition Analysis

The degree program Computational Mechanics in the Professional Profile Civil Engineering at the TUM School of Engineering and Design aims at offering a highly specialized curriculum to train highly motivated students at the frontier of numerical analysis and software implementation. This requires a very well-rounded curriculum that on the one hand side makes sure that each student gains basic competencies while on the other hand side allowing flexibility to ensure that the students can improve their individual skillset. Through its international orientation and broad range of applicable Bachelor studies as a prerequisite (comp. Section 3.2) the COME students support an interdisciplinary exchange and thus an atmosphere that promotes excellence in education and research.

The TUM School of Engineering and Design offers the degree program Civil Engineering, which offers education in solid and fluid mechanics as well as computational aspects in engineering applications. The Master's Program in Civil Engineering has a quite broad curriculum. Students must select four specializations out of 22. Thus, they can, for example, choose the four specializations Structural Mechanics, Computation in Engineering, Hydromechanics and Structural Mechanics. The courses offered by the Chair of Computational Mechanics are not offered in one specific specialization but can only be taken via an individually approved cross-sectional specialization. Furthermore, the structure of the COME program offers larger flexibility for students with different prerequisites to follow their initial background and newly found interests through including courses from various institutes at TUM within their individual curriculum. Also, the COME program has a stronger international orientation as compared to the Civil Engineering program. Focusing on the methods of Computational Mechanics allows the students to reach higher competencies in this field compared to civil engineering students. This is also emphasized by the curriculum, which contains modules which are either designed for this program (like "Software Lab") or are imported form the departments of mathematics, informatics or mechanical engineering (like "Bio Fluid Mechanics", "Scientific Visualization", "Functional Analysis"). Thus, the outreach of the graduates to industries and research entities far beyond civil engineering is considerably enlarged.

Furthermore, the TUM School of Engineering and Design offers the degree program Material Science and Engineering, which focusses on the description of complex physical and mechanical systems with a focus on the considered materials. Therein, a stochastic perspective is employed, allowing the graduates to design projects in material science scientifically and interdisciplinary. Since the program Computational Mechanics focusses more strongly on the mechanics and numerical modelling of structures and fluids in all fields of engineering, the program Material Science and Engineering can be seen as a fitting counterpart to COME to build an attractive portfolio for the education of highly specialized experts in numerical modelling of engineering problems.

The Department of Informatics at TUM offers the degree program Computational Science and Engineering (CSE) which combines applied mathematics with informatics and engineering to solve problems in science and engineering applications. In some parts both programs address the same issues, but CSE has a much stronger focus on computer science whereas the COME program addresses problems that require a deep understanding of the mechanical model at hand.

The Department of Mathematics at TUM offers the degree program Mathematics in Science and Engineering, which focuses on a solid education in applied mathematics, with focus on applied analysis or geometry, nonlinear optimization, numerical analysis or scientific computing. In parallel, the students are enabled to partly cover engineering tasks or work on problems in the natural sciences. As with the CSE program, there is some partial overlap in the addressed issues, but in contrast to COME the Master’s in Mathematics in Science and Engineering has a much stronger focus on a sound theoretical mathematical education. All three programs complement each other, building a strong foundation for highly relevant and excellent research in education in computational engineering at TUM.

The Master of Science in Computational Mechanics at TUM thus is a unique international degree program without comparable degree programs at TUM. In spite of the partial overlap with specific specializations of the Master’s program Civil Engineering, the curriculum of the Master’s program Computational Mechanics is significantly complemented with specific offers.

The degree program profits enormously from the events held by the relevant specialization areas of the Master´s programs Civil and Environmental Engineering. In the master´s program Civil Engineering, the relevant lectures are also taught in English. Therefore, a conscious decision was made to run the respective degree programs in joint groups, in order to encourage the students to mingle and get to know each other better (which is especially important for the high number of international students in COME). But still, as described above, the focus of the degree programs is different.

Altogether, the Master’s program Computational Mechanics is a unique program at TUM, focussing on the frontier of applied mechanics and computational implementation. It addresses its own broad group of interests, reflected in the diverse accepted pre-requisites and has an own well-tailored curriculum that enables graduates to work in a specific market with a broad application spectrum and high demand.

6 Program Structure

The standard duration of study of the Master's program Computational Mechanics is four semesters consisting out of three semesters of course work and one semester for the Master's thesis. The program has in total 120 ECTS credit points (CP), the three semesters and the Master´s thesis each worth 30 CP. The modular structure of the degree program includes required modules as well as elective modules. The 90 CP achieved through modules are divided into 40 CP of compulsory modules and 50 CP of elective modules. The elective modules are split into technical (in German: "fachspezifisch") elective modules (45 CP), and general education modules (5 CP). Within the technical elective modules two specialized elective module catalogs are introduced, namely modules from the catalogs "Mechanics & Modeling" and "Data, Uncertainty & Computing". Within the technical electives, students are required to take at least 12 CP from the catalog "Mechanics & Modeling" and 10 CP from the catalog "Data, Uncertainty & Computing". A general degree chart is depicted in Illustration 2. The two specialized catalogs include offers that can be included in the second and third semesters. Finally, students are allowed to include COME-relevant subjects from TUM or other universities that are not available in the catalog of technical electives as individual electives up to 12 CP. Overall, this program structure gives the students the required flexibility to include a stay abroad into their studies.

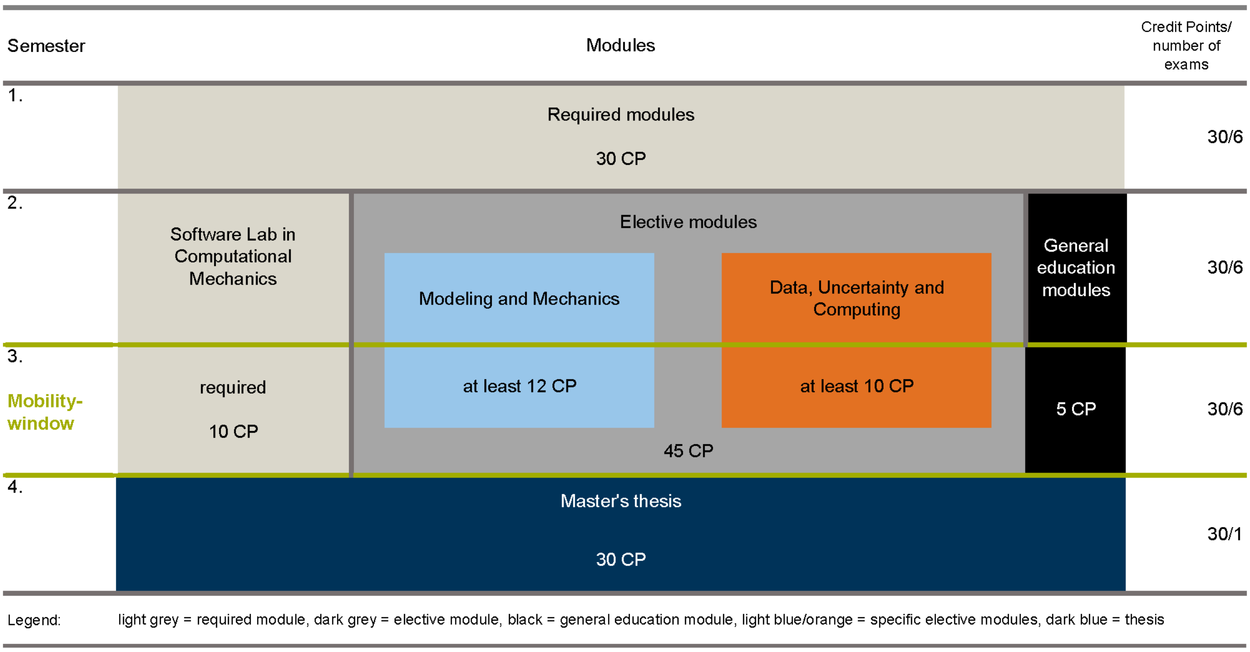

Illustration 2: Degree chart for Computational Mechanics

The academic background of the students of Computational Mechanics varies greatly. By means of the compulsory modules taught in the first semester, the students are able to reach the same level of expertise required for successful studies and above all to tailor the needs of industry and research. An overview of the required and specific elective subjects is illustrated in Illustration 3. After participating in the modules Computation in Engineering 1, Computational Material Modelling 1, Continuum Mechanics, Finite Element Method and Advanced Fluid Mechanics, the students learn about the most relevant theories, concepts and models and through that gain a solid background in mechanics (solid and fluid) and informatics (core competencies). In Computation in Engineering 1, the students learn about software engineering and object-oriented implementation in C++. After participating in Computational Material Modeling 1, the students are able to understand and apply mechanical models for different materials, e.g. linear and non-linear elasticity or various models for plasticity. In Continuum Mechanics the students learn about Tensor Analysis, and formulate the differential equations that govern the deformation of continuous media. In Finite Element Method, the students work on the solution of partial differential equations using the Finite Element method and inter alia cover the theoretical formulation, implementation aspects and specific engineering problems. Finally, in Advanced Fluid Mechanics, the students learn about the treatment of flow phenomena and how to apply higher mathematics to solve such problems. With this, we ensure that the students obtain the necessary foundations in continuum mechanics and fluid mechanics on the one hand, and the numerical solution of therefrom resulting complex differential equations, as stated in Section 2.

Required	Computation in Engineering 1 6 CP	Computational Material Modeling 1 6 CP	Continuum Mechanics 6 CP	Finite Element Method 6 CP	Advanced Fluid Mechanics 6 CP	
Modeling & Mechancis	Computational Material Modeling 2 6 CP	Computational Fluid Dynamics (CFD) 6 CP	Structural Dynamics 6 CP	Theory of Plates 3 CP	Theory of Shells 3 CP	Advanced Finite Element Method 3 CP
Data, Uncertainty and Computing	Optimization 6 CP	Artificial Intelligence in Computational Mechanics 6 CP	Advanced Parallel Computing and Solvers in Engineering 5 CP	Introduction to Functional Analysis (BV/COME) 5 CP	Stochastic Finite Element Methods 6 CP	

Illustration 3: Overview over the required (except Softwar Lab in Computational Mechanics) as well as specific elective modules in the two catalogs “Mechanics & Modeling” and “Data, Uncertainty & Computing”.

The module Software Lab in Computational Mechanics” (SL in COME) (10 CP) is taught in the second and third semesters and builds upon the core fundamentals gained in the first semester. It is an interdisciplinary team project (3-4 students) that links the analysis and the solution of engineering problems and the development of software components by processing a complex software project (industrial or research projects).
To allow the students to make contacts in industry and introduce them to industrial issues, co-supervisors from industry are often involved in the assignment and supervision. Through implementing their own software code that solves a typical, yet advanced engineering problem, they gain very strong methodological competencies. By requiring intermediate presentations, a realistic, project-based work protocol is established, which prepares the students well for later work and research. Through group work in small teams, they gain experience in working together in multicultural groups and are sensitized to the importance of dealing with cultural differences.

The two-semester period of the SL in COME is also based on the enormous computational effort. The computer clusters may require computing times between several days and weeks between the programming steps. In any case the students must always coordinate and discuss their own implementations in various iterations, which requires a longer project time. In addition, the students are given more time flexibility for processing. For example, they can reduce the workload for the SL during the regular examination phase of the second semester (usually in August and September) and then flexibly increase it again. Furthermore, through the parallel technical modules, students can gain valuable thematic links during the semesters.

The students can easily manage their projects using online tools and hold project meetings in digital form, so processing is also guaranteed during a stay abroad. Thus, student mobility is possible without compromising the standard duration of study in the third semester.

In the second and third semesters, the students have to gain 12 CP and 10 CP out of the modules in the elective module catalogs “Mechanics & Modeling” and “Data, Uncertainty & Computing” (see FPSO). These elective modules are required to specialize the students’ fields of interest and create their own professional profiles. Simultaneously, it maintains a clear degree program profile. These modules also potentially help in selecting an appropriate direction for a Master’s thesis. Furthermore, the students obtain the necessary competencies to critically reflect on simulation results and identify numerical artifacts. Through modules in the elective catalog “Mechanics and Modeling”, the students obtain important competencies in the mechanical modeling of engineering problems. In contrast, modules in the elective catalog “Data, Uncertainty & Computing” give a deeper understanding on the implementation and solution strategies that are required to solve the formulated mechanical problems. Furthermore, it equips the students with novel methodologies such as artificial intelligence, which is required for COME students nowadays, as well as the increasingly more relevant field of uncertainty quantification. By requiring the students to choose subjects from both catalogs, we enable the students to gain competencies that link the fields of mathematics, informatics, and mechanics. Through modules like ‘Computational Fluid Dynamics’, ‘Structural Dynamics’ or ‘Computational Material Modeling 2’, the students gain competencies in the computation of various system responses for complex structures and loading scenarios. Through modules like ‘Advanced Finite Element Method’, the students gain deeper fundamental knowledge in the basics of the solution of problems in solid mechanics as well as numerical analysis and its computer implementation. Modules like ‘Artificial Intelligence in Computational Mechanics’ open the field of Computational Mechanics to new research fields of ever-increasing importance. The module ‘Stochastic Finite Element Methods’ introduces the concepts of uncertainty and stochastic modelling and their incorporation into mechanical models as well as the numerical treatment. The modules of both of these elective catalogs build upon the core competencies taught in the compulsory modules.

Three exemplary degree charts are shown for students with a focus on fluid mechanics or a focus on solid mechanics in Illustrations 4 to 6. Illustration 4 highlights a degree chart, which covers the fundamental subjects in COME through choosing many elective modules from the specific elective subjects in the field “Mechanics & Modeling” and “Data, Uncertainty & Computing”. Illustration 5 shows a specific curriculum design that focusses strongly on the field of fluid mechanics and dynamics. It includes elements from biofluid dynamics, computational thermo-fluid dynamics and modeling of turbulent flows and therefore allows an in-depth training of experts in the field of fluid mechanics. The choice of specific elective subjects underpins the specific choice with the necessary fundamental methodological basis. On the other hand, in Illustration 6, the degree chart illustrates a study plan, which focusses on the field of solid mechanics, dynamics and acoustics with strong emphasis on numerical methods from machine learning. The curriculum is rounded off by an individual study project that allows to deepen the scientific competencies of the student. Courses such as “Deep Learning of PDEs for Engineering Physics” or “Scientific Computing and Machine Learning” equip the students with the increasingly popular techniques of machine learning and artificial intelligence and allow to foster these methods for the development of efficient numerical techniques in the classical fields of structural dynamics and acoustics, introduced through the modules “Structural Dynamics” and “Computational Acoustics”.

Semester	Modules						Credits/ number of exams
1.	Computation in Engineering 1 (Required) Written exam + Coursework 6 CP	Computational Material Modeling 1 (Required) Written exam 6 CP	Continuum Mechanics (Required) Written exam 6 CP	Finite Element Method (Required) Written exam + Coursework 6 CP	Advanced Fluid Mechanics (Required) Written exam 6 CP		30/6
2.	Software Lab in Computational Mechanics	Artificial Intelligence in Computational Mechanics (Elective) Written exam + Project work 6 CP	Structural Dynamics (Elective) Written exam 6 CP	Advanced Parallel Computing and Solvers in Engineering (Elective) Written exam 5 CP	Advanced Finite Element Method (Elective) Written exam 3 CP	General education module (Elective) pass/fail credit requirement 5 CP	30/6
3. Mobility window	(Required) Project Work 10 CP	Computational Material Modeling 2 (Elective) Written exam 6 CP	Introduction to Functional Analysis (Elective) Written exam 5 CP	Stochastic Finite Elment Methods (Elective) Project work 6 CP	Scientific Visualization (Elective) Project work 5 CP	Modeling and Simulation in Structural Mechanics (Elective) Project work 3 CP	30/6
4.	Master's thesis 30 CP						30/1

Legend: light grey = required, dark grey = elective, black = general education, light blue/orange = specific elective, dark blue = thesis

Illustration 4: Degree chart example 1, with broad elective spectrum, many elective subjects taken from the specialized elective catalogs.

Semester	Module						Credits/ number of exams
1.	Computation in Engineering 1 (Required) Written exam + Coursework 6 CP	Computational Material Modeling 1 (Required) Written exam 6 CP	Continuum Mechanics (Required) Written exam 6 CP	Finite Element Method (Required) Written exam + Coursework 6 CP	Advanced Fluid Mechanics (Required) Written exam 6 CP		30/6
2.	Software Lab in Computational Mechanics	Computational Fluid Dynamics (Elective) Practical requirement 6 CP	Structural Dynamics (Elective) Written exam 6 CP	Modeling and Simulation of Turbulent Flows (Elective) Written exam 6 CP	Biofluid Mechanics (Elective) Scientific work 5 CP	General education module (Elective) pass/fail credit requirement 2 CP	30/5
3. Mobility window	(Required) Project Work 10 CP	Optimization (Elective) Written exam 6 CP	Stochastic Finite Elment Methods (Elective) Written exam 6 CP	Structural Wind Engineering (Elective) Project work 6 CP	Study Project in Computational Mechanics (Elective) Written exam 4 CP	General education module (Elective) pass/fail credit requirement 3 CP	30/6
4.	Master's thesis 30 CP						30/1

Legend: light grey = required, dark grey = elective, black = general education, light blue/orange = specific elective, dark blue = thesis

Illustration 5: Degree chart example 2, with focus on fluid mechanics.

Altogether, the different degree charts show that the students can flexibly choose combinations of different modules, which is important to allow the students to find suitable specializations that suit their interests and career goals. Furthermore, it allows to guarantee a stay abroad, while the two specialized elective catalogs make sure that all students gain specific required competencies in industry and research.

The elective modules allow getting a wide knowledge in different disciplines as they can be chosen also from other related TUM schools or departments such as civil engineering, mechanical engineering or informatics up to 12 CP. The students are also free to deepen their knowledge within this catalog and thus get even more knowledge in solid or fluid mechanics, programming or industrial applications, thus sharpening their individual professional profiles. The elective modules also tackle more research-oriented topics and enable the students to work on highly relevant problems, which opens them to identifying and articulating their own research questions. By this, they are prepared to continue their work in research and academia, where they can receive doctoral positions. In particular, students can choose to do a study project in Computational Mechanics. We allow students to define a research-oriented proposal based on their interests on which they can work independently. The workload is agreed upon with the supervisors and usually ranges between 90 and 180 work hours, corresponding to 3 to 6 ECTS. The list of possible elective modules is subject to change in order to meet the requirements of the industry and the fields of interest of the students. It can be found (always up to date) on the webpage of the program, see www.come.tum.de. Students are informed about the update prior to the start of the semester.

Furthermore, the students need to select general education modules with 5 CP in total during their studies to enhance the students' self-competencies and soft skills. Modules from the Language Center, the Center for Key Competencies at the TUM School of Engineering and Design, Contextual Teaching Science ⋈ Technology ⋈ Society and specific courses offered by the faculties and institutes involved in the degree program shall allow students to tackle their own self-understanding and improve their social and soft skills, their language proficiency, as well as tackle state of the art questions on ethics in engineering or artificial intelligence. These courses will help the students to critically reflect upon their own academic and professional self-understanding and the impact of modern technologies on the environment and society. Furthermore, training in cross-cutting competencies and general education are intended to be included across the curriculum. Exemplarily, newly developed blended learning offers for project-based learning by the Center for Key Competencies at the TUM School of Engineering and Design will be included in the redesigned and extended module 'Software Lab in Computational Mechanics'. Through this, students receive targeted and hands-on training in subjects such as project management, group organization or scientific presentation.

The Master's thesis takes 6 months and can be written either at the chairs involved in Computational Mechanics or in cooperation with industry or other academic partners (e.g., Frauenhofer Institute). The students always need a supervisor at one of the chairs involved in Computational Mechanics or a suitable supervisor from within the TUM School of Engineering and Design. Often, the Master's thesis opens the doors to a PhD-position at the university or a job offer in industry after graduation.

The examination types have a wide range to enable the students to gain all required competencies within the Master's program. These include the competence to present their work, which is taught through smaller modules like "Modelling and Simulation in Structural Mechanics" and through the Master's Thesis. Furthermore, through a couple of smaller project works, as within the module "Computation in Engineering 1" or the examination type "practical credit requirement" in the module "Computational Fluid Mechanics (CFD)" we make sure that the students have valuable hands-on experience in computer programming. The competence to critically reflect on the simulation results and structural or fluid system prediction is taught inherently within most of the modules in the curriculum.

Semester	Modules						Credits/ number of exams
1.	Computation in Engineering 1 (Required) Written exam + Coursework 6 CP	Computational Material Modeling 1 (Required) Written exam 6 CP	Continuum Mechanics (Required) Written exam 6 CP	Finite Element Method (Required) Written exam + Coursework 6 CP	Advanced Fluid Mechanics (Required) Written exam 6 CP		30/6
2.	Software Lab in Computational Mechanics	Artificial Intelligence in Computational Mechanics (Elective) Written exam 6 CP	Structural Dynamics (Elective) Practical requirement 6 CP	Study Project in Computational Mechanics (Elective) Written exam 4 CP	Deep Learning for PDEs in Engineering Physics (Elective) Written exam 4 CP	General education module (Elective) pass/fail credit requirement 5 CP	30/5
3. Mobility window	(Required) Project Work 10 CP	Computational Material Modeling 2 (Elective) Written exam 6 CP	Stochastic Finite Element Methods (Elective) Written exam 6 CP	Computational Acoustics (Elective) Project work 5 CP	Scientific Visualization (Elective) Written exam 5 CP	Modeling and Simulation in Structural Mechanics (Elective) Project work 3 CP	30/6
4.	Master's thesis 30 CP						30/1

Legend: light grey = required, dark grey = elective, black = general education, light blue/orange = specific elective, dark blue = thesis

Illustration 6: Degree chart example 3, with focus on structural mechanics, acoustics and machine learning.

Modules in the field of Computational Mechanics which are obtained during the Master's program at another university (e.g. during an international exchange) can be recognized.

TUM is offering four different types of exchange programs for Computational Mechanics students:

- Erasmus-Program (studies within Europe)
- TUMexchange (studies outside Europe)
- EU Mobility Programs (studies in selected regions outside the European Union (EU))
- ATHENS (one-week courses within Europe)

Especially the ATHENS program - which is offered twice a year - attracted many of the COME students in the last years. The compulsory module "Software Lab in Computational Mechanics" within the second and third semester is designed that way, that students are still able to go abroad or perform exchange studies within another German university. Thus, the module can be done online and also the examination, a project work, can be handed in and be presented digitally. Thereby an unrestricted mobility without extended study times is made possible.

In the last years not many students were interested to go abroad since many of the students especially come to Germany to join the program. Therefore, there is not as much interest in studies abroad as in other degree programs. Still, a stay abroad or at another German university is supported and possible. Further information can be found on the dedicated sections on the school's webpage.

For the formal design of the degree program (module size, exam design) the Ländergemeinsame Strukturvorgaben ("Common Structural Guidelines") were considered. The study plans verify the ability to study the degree program. The modules, especially in the compulsory catalog, mostly have an extent of a minimum of 5 CP. Deviations occur for the general education modules (2 and 3 CP) and in the technical modules. In the last, we explicitly also list smaller modules besides the modules with larger extent to give the students specialized insight into different areas of structural and fluid mechanics. Additionally, we aim at allowing for a higher degree of flexibility in the study design. In the exemplary study plans, we therefore enter a 3 CP elective module in the third semester, at the same time the maximum number of examinations of 6 exams per semester is not exceeded.

7 Organization and Coordination

The Master's Program in Computational Mechanics is offered at the Department of Civil, Geo and Environmental Engineering of the Technical University of Munich, where it is jointly taught by professors of the Focus Area "**Modeling-Simulation-Processes**". The following chairs (professors) are mainly involved in the teaching of the degree program:

- Computational Modeling and Simulation (Prof. Borrmann)
- Structural Analysis (Prof. Wüchner)
- Structural Mechanics (Prof. Müller)
- Computational Solid Mechanics (Prof. Duddeck)
- Hydromechanics (Prof. Manhart)
- Engineering Risk Analysis (Prof. Straub)

Several elective modules can be attended at the Department of Mechanical Engineering and the Department of Informatics. As it is an interdisciplinary degree program many other chairs and departments of the TUM are involved.

The following administrative tasks are performed partly by the TUM Center for Study and Teaching (TUM CST) and its administrative units, partly by offices in the schools or departments:

- Student Advising: Student Advising and Information Services (TUM CST)
Email: studium@tum.de
Phone: +49 (0)89 289 22245
Provides information and advising for prospective and current students (via hotline/service desk)
- Departmental Student Advising: Program Coordinators and Academic Advisors
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Phone: +49 (0)89 289 28322
+49 (0)89 289 28393
- Academic Programs Office: Examination Administration and Advising
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- Study Abroad Advising/Internationalization:
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  Admissions, enrollment, Student Card, leaves of absence, student fees payment, withdrawal
- Aptitude Assessment (EV): TUM-wide: Advising and Information (TUM CST), Admissions and Enrollment
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  Campus Munich/Garching/Weihenstephan/ Klinikum rechts der Isar
  Graduation documents, notifications of examination results, preliminary degree certificates

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- Examination Board: Prof. Dr.-Ing. Gerhard Müller (Chair)
  Samanta Castellarin (Secretary)
- Quality Management: TUM-wide: Quality Management (TUM CST),
  https://www.tum.de/studium/tumcst/teams-cst/
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8 Enhancement Measures

The program has been adapted to changing boundary conditions several times since its foundation in the year 2000. As the boundary conditions change, also the program has to be modified continuously. The boundary conditions are defined by the requisites of the Bavarian Universitisy Act (German: Bayerisches Hochschulgesetz, BayHSchG). The specifications enacted by the German Standing Conference of the Ministers of Education and Cultural Affairs (German: Kultusministerkonferenz, KMK) and the accreditation.

Examples for recently adapted boundary conditions are the maximum number of examinations per semester or minimum number of credits per module. Furthermore, issues formulated by students (and their representatives) in different boards of the department (PP conferences, department meetings, quality management boards) are discussed and finally brought into the structure of the program. Furthermore, the curriculum was adapted in 2020, and the required-elective catalogs were reorganized into elective catalogs “Mechanics” and “Computation” representing mechanics and computational-oriented modules in order to implement a clearer structure. We introduced the module “Artificial Intelligence in Engineering” as a computational elective module to take account of this increasingly important aspect in computational science. Also, we made sure that the mobility window can be used without any barriers to increase student mobility.

In the scope of the program redesign in 2025, the elective catalogs were slightly reorganized. The two specialized elective catalogs were renamed into “Mechanics & Modeling” and “Data, Uncertainty & Computing” and extended by one module each. Furthermore, a clearer structure could be implemented by incorporating these catalogs into the general technical elective catalog and thus increasing transparency and handling for the students. The important subject of parallel computing for complex engineering structures was revived by incorporating the module “Advanced Parallel Computing and Solvers in Engineering” into the “Data, Uncertainty & Computing” catalog. Furthermore, we introduced further elective courses from other departments and schools to account for the versatility of the field and the background of our students. Especially, offers from the department of mechanical engineering have been included. This reflects the great expertise available at the TUM School of Engineering and Design in the field of numerical modelling in mechanics, which we make accessible to our students. Finally, the credits for the Software Lab in Computational Mechanics have been increased from 6 to 10 ECTS to account for the increased workload, which has been reported by students.

To increase the visibility of female students and their success stories in Computational Mechanics, we updated our webpage and included an interview with two of our students in cooperation with the communications team at the TUM School of Engineering and Design. We hope to inspire more female students to start their studies of Computational Mechanics in the future.

Furthermore, we are constantly striving to include diverse, modern and innovative forms of teaching and examination within the program.