Digitalization in Construction, Computer-based Design for Structural Elements - Analyses and Validation of Compliance to EuroCodes

Project Description

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The constant development and progress in construction industry requires qualified and competent engineers. Digitalization and Industry 4.0 are the keywords leading to the professional future. These new challenges do not only impact the working environment, they have to be considered on the level of higher education at universities, too. The students need to be prepared for this fast-changing market, so course programs have to be adapted and updated to reflect and incorporate the technological changes. An up-to-date curriculum will then offer new opportunities for graduated students leaving the universities. But also professional engineers with long-time practical experience will be in need of further training to get prepared for their ever-changing work environment. Especially for civil engineering which is more and more relying on digital data models of the buildings, the profile of engineers will change in the future. Based on digital data models, computational engineering becomes increasingly important. Thus, the future working place of structural civil engineers who take care of the design and dimensioning of structural elements, will be dominated by computer-based advanced design methods. Profound in-depth knowledge regarding the validation and assessment of its results will become essential.

A classic structural analysis is characterized by the use of a wide spectrum of manual, specialized analysis methods. An engineer has to break down the complex problem into small manageable sub-problems. This procedure will be completely superseded by the advent of numerical methods. A full model of the spatial structure will be built up. A similar revolution has already begun by the introduction of finite shell and volume elements into commercially available FE software. The idea is that these models are closer to reality and allow us to capture both global and local effects in one single comprehensive model. This, however, introduces modelling questions and numerical effects, which are explicitly excluded from simplified theory, and questions arise regarding the trustworthiness of these results. Shell elements have already been fairly well established in practical engineering. The next step could be the use of volume elements to overcome certain restriction inherent in shell formulations. One driving force for this tendency is BIM (Building Information Modelling). Here the geometrical model is, like nature itself, fully 3D. It can be directly translated into the Finite Element Method (FEM). However, structural design in the 27 EU member states and 4 EFTA countries has to be performed according to the Eurocodes (EC), representing harmonized European Standards (EN) for the structural design. These design codes regulate essential requirements regarding mechanical resistance and stability as well as safety aspects. The current Eurocodes essentially stipulate engineering design models which can easily be transferred to classical structural analyses, but often do not give comprehensive references to the application and evaluation of advanced numerical simulations. The application of associated software products is not regulated by norms. This situation often results in discussions and different interpretations of the design results. Ultimately, false computational assumptions and misinterpretations can lead to damages and unsafe design.

In education, the courses on numerical methods are often separated from the courses for structural design. Of special interest for this project are the design methods for reinforced concrete (EC 2), steel (EC 3) and composite (EC 4) structures. This unsatisfactory situation is the point where the project idea came up and where this project started. In the literature, much information regarding the theory of the Finite Element Method is already available. It is important to link theory with the application in the field of structural engineering. Students should learn how to proceed when performing a numerical analysis of a structural component and how to assess the results in accordance to the Eurocodes. The interpretation of those results is essential. Last but not least, guidance for the verification of the software results is required and the link to the current and upcoming second generation of Eurocodes is also presented by the project. In parallel the possibilities by digitalization in construction by Building Information Modelling and the transfer of data from the architectural model to the structural model have been investigated.

Based on the described challenge the project idea was developed by the partners of University of Wuppertal, University of Science and Technology Wroclaw and the Trier University of applied science under the coordination of the University of Luxembourg to address the issue and to develop new course contents with the objective of preparing the students for future job market. It was decided to investigate in three different intellectual outcomes:

Intellectual Output 1 (IO1) regards the analysis of the impact and the possibilities of digitalization in construction. It presents a state of the art for building information modelling. Within IO1, new digital technologies related to BIM, data transfer and challenges are presented as well as chances and difficulties encountered in their application. Thereby, available standard software for the development of digital data models has been tested to discover the possibilities by the new technologies. Especially in this part many students have been involved. Based on cross-border cooperation of the partners the principles of BIM and examples based on a jointly developed model building have been elaborated, followed by individual student works on different tasks. The project is not only demonstrating the challenges and opportunities by the digitalization, it also points out where problems occurred and that the transfer of data by different software packages often need manually correction by the structural engineer. However, it is also noted that the market is developing and changing very fast. Software producers are providing regular updates to increase the quality and to adopt the applications to the ongoing state of the art. Following the very fast market development it becomes also visible that future engineering job market will concentrate on the digital building data models and that will be a standard tool as today the CAD drawing. In addition, in the project a survey analysis of the state, experiences, expectations and risks by digitalization in structural engineering has been developed and conducted. This survey was addressed to structural engineering offices. The feedback obtained from the structural engineering community represents the current market position and situation of structural engineering offices regarding digitalization and allows a very interesting view on the current situation, the expected challenge and how the market will prepare for it.

Intellectual outcome IO2 consists of a scriptum where the compliance of designs based on computational engineering to the European Design Codes is addressed. In these studies, the application of advanced numerical design methods, e.g. FE analyses with shell and volume elements (linear and non-linear solution methods) considering geometrical or/and physical nonlinearities, has been investigated. The question was discussed how far it is possible to apply advanced numerical methods, in particular FEM, within the concepts of the Eurocodes so that the stipulations of the code, e.g.

regarding safety levels, are not violated. Information has been provided considering the theory of FEM, its application, the safety concept, solver methods, imperfections and residual stresses and the validation and assessment of the results.

For this IO introductory chapters on the development of the theory of structures and on the finite element method were written. A wide spectrum of basic numerical has been developed, analyzed, and worked out. The overall theme has been the question in how far 2D and 3D element types can model beams, shells and continua. The test examples systematically investigate

- the behaviour of different element types: classes of surface and continuum elements;
- the capabilities and limitations and the performance of different software products;
- the application to problems of linear static and linear stability.

These benchmarks bear no immediate relationship to Eurocodes, but address the general applicability of the finite element method. These general insights then form the basis for the practically oriented benchmarks which in their turn investigate the applicability of FEM to specific, more complex problems. Finally, a long theoretical chapter on geometrical nonlinearity and path-tracing algorithms has been written which forms the theoretical basis of the simulation of nonlinear analyses compliant with the Eurocodes, in particular stability problems and nonlinear material models.

Another milestone of IO2 was the part about Eurocodes with focus on introduction and theoretical basics, with focus on assessment and applied numerical design considering

- reinforced concrete structures according to Eurocode 2
- steel structures according to Eurocode 3
- composite structures in steel and concrete according to Eurocode 4
- composite structures in timber and concrete in reference to Eurocode 5.

Many detailed information are provided about the application of FE Analysis, approach of imperfection, residual stresses and the assessment of the analysis.

Finally, case studies and examples have been developed by the support of students and academic staff. In addition tutorial are available to show the modelling process for different software application. Those tutorial will help students to obtain a quick introduction to modeling and numerical analysis.

Intellectual Outcome IO3 is representing a seminary presenting selected topics from the intellectual outcomes IO1 and IO2. While the presentation of these outcomes was originally planned to take place in a series of seminars at the partner universities' campuses, the COVID19 restrictions changed this to an online Summer School. This multiplier event was a great success, with participants from ten difference countries..

One of the main ideas of the project was to involve the students of the partner universities to a large extent in producing the intellectual outputs. So, since the students are the target group of the project, it was necessary to build the project on the capabilities and skills of the students. By their very nature, the numerical analyses have been challenging, going beyond basic knowledge, which required intensive tutoring of the students by the academic staff.

Overall conclusion is: the project was a challenge for all involved persons regarding the special circumstances by COVID19, but it was nevertheless successfully completed. Some of the project outcomes have already been integrated in the teaching programs and will be freely accessible for the public by the project homepage. Students and academic staff were able to gain new experiences and expand their knowledge through the project work. The project certainly represents a starting point with regard to digitalization and in cooperation with the partners and network of the universities the topic will certainly be deepened in the future.

Disclaimer

The project provides information about digitalisation in construction and advanced numerical design methods. The material and outcomes are to be understood as addi-tional teaching material but not as design guidelines or information to be used as models for the design of engineering structures. Some of the background is explained without any connection to the current design regulations and codes, and in other parts reference is made to the regulations of the next generation of Eurocodes, which have not yet been introduced and may still change in future. The outcomes are intended as help to understand the challenges posed by digitalization and application of numerical design for design examples. The application of the various calculation methods and the design is the responsibility of the structural engineer and must rely on the design codes, e.g. Eurocodes, and official design rules. Therefore, the readers themselves should always consult the original codes and other publications, handbooks and de-sign guides, and design according to the codes currently in force. It has never been the target of the project CavaEuroCodes to develop an official design guide and therefore the outcomes must not to be understood as such a document.

Even if the Universities involved in the project have carefully worked out the results, it has to be emphasized that many project works and case studies incorporated in CavaEuroCodes represent student works of Bachelor and Master students and not scientific publications. Here the Universities, the Authors and Co-authors do not assume any liability and responsibility for the use of the project outcomes or consequences resulting from the use of it, they give no warranty and accept no responsibility or liability for the accuracy or the completeness of the information, materials and out-comes of the Erasmus+ project. Under no circumstances will the Universities, the Authors and Co-authors be held liable or responsible in any way for damages, losses, expenses, costs, claims or other liabilities resulting directly or indirectly from the use of the information, materials and outcomes as well by the use of the website.

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