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

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Preface

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 usage 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 This procedure will be completely superseded by the advent of numerical methods.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 designs.

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. For the project, however, it became important to link the 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.

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.

The project started in September 2018 and have been finalized by August 2021. Of course, such an international project could not have been immune the adverse effects the world-wide COVID-19 pandemic. It was, like all walks of public and private life, heavily impacted. Due to the COVID restrictions and lock-downs the university campuses were not accessible anymore. Both teaching and student supervision had to be re-organized completely to allow online teaching and tutoring for a period of three semesters. This challenge was very labour-intensive and tied up many resources. Therefore, the main difficulties encountered by the Erasmus+ project had been caused by the lockdowns and their consequences. The scheduled transnational project meetings had to be organized online and neither the blended mobility weeks nor activities, exchanges, physical supervision or the training of the students could not take place as planned. We learned that digitalization became a driving element in teaching but it became also apparent that all the electronic communication channels cannot adequately substitute personal meetings. In general, many students had problems during the three semesters of online teaching, not only due to the remote lectures but rather through limited social contacts. Due to the cancelled blended activity events the exchange between the students and staff of the involved universities and the cultural exchange, which is also an important part of the Erasmus idea, could not be realized as intended. Much effort was spent in the supervision and support of the students.

Despite all the difficulties outlined above, the projected three intellectual outputs have been successfully produced during the project. 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. In addition, a survey analysis of the state, experiences, expectations and risks by digitalization in structural engineering has been developed and conducted. The feedback obtained from the structural engineering community represents the current market position and situation of structural engineering offices regarding digitalization. The second 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. Some selected topics were presented during the Summer School organized by the project partners in July 2021. This multiplier event was a great success. About 180 participants from ten different countries took part in this online event. The contents of the Summer School are summarized in IO3.

Overall conclusion is: the project was a challenge for all involved persons regarding the special circumstances, 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. 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. The project coordinators thank all students and academic staff for their contributions and motivation.

The project partners express their heart-felt gratitude to the EUROPEAN COMISSION for the acceptance of the project proposal and for their funding, and the National Agency ANEFORE for the support and management of the project.

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The project Coordinators

The project outcomes are published as digital scriptum online free accessible via:

https://isaweb.hochschule-trier.de/cava-eurocodes/

Public password: cava-eurocodes_2021

Disclaimer

The project provides information about digitalisation in construction and advanced numerical design methods. The material and outcomes are to be understood as additional 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 design 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 outcomes 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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IO 2: Computer based design for structural elements in accordance with Eurocodes

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