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New Ways of Teaching Statics and Applied Structural Mechanics to Architects

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Abstract. Education of exact and technical subjects at traditional schools of architecture faces a difficult task to bring these disciplines to students of significantly lower technical perception, now. For this reason, at the Faculty of Architecture, Czech Technical University in Prague, a series of seminars containing the design of physical and virtual models completed by measuring and static calculations to supplement existing education of statics and applied structural mechanics is currently prepared.

Introduction

There is a significant increase of the number of architectural students in the Czech Republic during the last twenty years.

In addition to the existing traditional faculties which had been teaching *„Engineers Architects“* (Czech Technical University in Prague (CTU in Prague) and Technical University in Brno) and former *„Academic Architects“* (Academy of Applied Arts in Prague and Academy of Fine Arts in Prague), architectural education has been introduced also at other public faculties and universities (such as the Faculty of Civil Engineering of the Czech Technical University in Prague, Technical University in Brno, Technical University of Ostrava and the Technical University of Liberec) and the number of architectural students has grown almost ten times in a comparison with the situation twenty years ago.

Recent developments show an increasingly pronounced polarization in education of exact and technical subjects, when the newly established architectural education at the technical faculties and schools de facto extend previous studies of civil engineering and orient their education of architecture significantly in more technical direction and on the contrary, traditional schools of architecture show some efforts to simplify teaching of exact and technical subjects.

Share of Structural Engineering in Curricula at Selected European Universities

An introductory study (accepted for ICQH Conference 2013, Sakarya, Turkey) analyzing share of structural engineering in curricula at selected European universities has been made at the Faculty of Architecture, Czech Technical University in Prague. The main objective of the study was to analyze the importance of Structural Engineering in university courses of Civil Engineering and Architecture. The study compared Czech Technical University with leading European universities on this criterion (percentage share of Structural Engineering in curricula, volume of ECTS credits devoted to Structural Engineering). For the initial

comparison, four leading German and English speaking European universities were taken into account. (CTU – Czech Technical University in Prague, Czech Republic [1,2], TUM– Technical University of Munich, Germany [3], ETH – ETH Technical University of Zurich, Switzerland [4], UB – University of Bath, United Kingdom [5], ICL- London Imperial College, United Kingdom [6]). The selection was conducted on the basis of several rankings listed at the end of this article [7, 8, 9, 10, 11, 12]. Following observations has been made:

1. Structural Engineering represents around 20-40% of Civil Engineering curricula.
2. In Architecture Courses, it represents less than 15% of bachelors and 0-5% of master's curricula.
3. Architectural Engineering (combination of Architecture Design and Civil Engineering) is available only at University of Bath (where share of Structural Engineering in combined courses corresponds to such share in Civil Engineering, i.e. it is between 20-40% across the length of the study, with its share growing in the master courses) and at the Czech Technical University in Prague (where Structural Engineering is not lectured in its master combined courses at all).
4. London Imperial College has the highest share of Structural Engineering in Civil Engineering across duration of all its courses (42% bachelor, 36 % master), closely followed by Technical University of Munich (30% bachelor, 40% master). Technical University Munich also displays the highest share of Structural Engineering for its Architectural Design courses (12% bachelor, 5% master).
5. The Czech Technical University in Prague has the lowest share of Structural Engineering in its Civil Engineering courses [2] (22% bachelor-26% master). In Architectural Design Courses [1], Structural Engineering has relatively low share on curriculum at each stage of the study out of the universities that teach Structural Engineering as part of those courses. However, it is the only university out of our sample that teaches structural engineering both in bachelor and master courses in architecture.

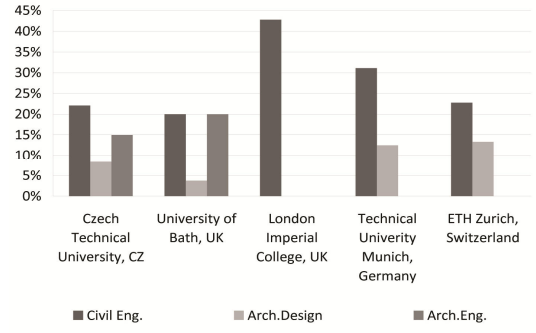

Fig. 1. Structural Engineering as a % of Curriculum, Bachelor.

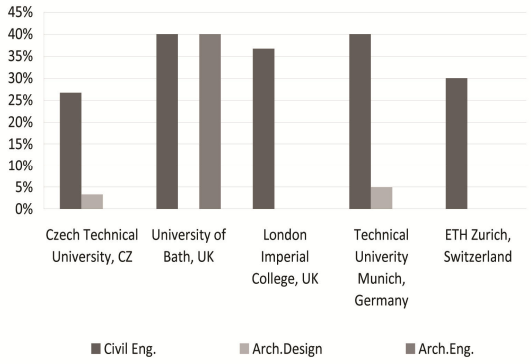

Fig. 2. Structural Engineering as a % of Curriculum, Master.

As is widely known, Structural Engineering plays reduced role in Architecture Courses in a comparison to Civil Engineering Courses. However, relatively high percentage of Structural engineering in curricula of some universities might reflect the setting trend of putting bigger impact on its deeper understanding. To validate this hypothesis, further analysis (e.g. detailed content of the courses or issue of putting different emphasis on teaching different subject and explaining why) is currently undergoing with the specialization on architectural courses only and broadening the number of selected universities to twenty.

Innovative Methods in Teaching Structural Engineering

At present, the Faculty of Architecture, CTU in Prague, is looking into successful innovative teaching tools. (applied at MIT Boston [13] or ETH Zurich for teaching structural analysis both to its civil engineering and architecture students) with the prospect of introducing them as a part of its own courses in statics.

One of them is an *Easy Statics* program developed exclusively for teaching purposes by Claudia Pedron between the years 2001-2006. The program is intended to be the basic and fundamental one with the intention to help undergraduate students understand how loaded structures mechanically behave. It has been designed as a kind of "laboratory" where students can create simple plane and truss structures with no predefined geometry, under arbitrary load and support conditions and with elements of different sizes and materials, by which after any model change, the results are computed and immediately shown. According to Pedron [14], students can improve their understanding of structures by observing how parameters changes do affect structural behaviour. Interactive manipulation with the model let students compare different structural situations and make a judgment, why one design appears to be better than another.

Second program worth mentioning is *eQuilibrium* – an interactive, graphic statics-based learning platform for structural design created by Philippe Block, BLOCK Research Group [15], which development started in 2010.

Graphical methods offer powerful techniques for the analysis of structures. Often, the effort required is much less than that one required by theoretical methods and the solution is comparably accurate. Carl Culmann, founder of graphic statics, held the chair of engineering sciences at Swiss Federal Institute of Technology (ETH) in Zurich from 1855 until his death in 1881. The main principle of graphic statics is using force polygons and simple geometric construction techniques, which provides us with visual information about the relation between form and forces in a structural system. The *eQuilibrium* program is created with the support of *GeoGebra* software, which allows users making graphic statics constructions without programming skills. As stated on BLOCK Research Group website, the elements that make up the drawing can be dynamically changed afterwards to interactively explore the relation between form and forces with real-time visual feedback. Therefore, the combination of graphic statics and *GeoGebra* provides an interesting and engaging way to illustrate and explain the behaviour of structures and allows users to quickly start making their own drawings for their structural analyses and design explorations.

Contemporary advocate for graphostatics methods for lecturing on structures is the team of Karl-Eugen Kurrer [16], according to whom the clarity of graphical techniques has a high didactic value, since interdependencies, e.g. between forces and structural geometry, can be directly experienced visually.

Simultaneously, at the Faculty of Architecture, CTU in Prague, a series of innovative seminars on structural mechanics based on graphic statics is being prepared.

As a consequence of a weak basis in technical subjects knowledge of the students entering architecture, there is a need to modify existing seminars on structural mechanics. This should lead to a deepening and strengthening of required knowledge and to the adoption of its basic principles. The aim of this pilot project is to provide additional grounding in the field of load-bearing structures, its type and material properties while supporting the development of intuitive design of a structure. All of these components, especially the geometry of structure are in the hands of architects – that´s why architects should be familiar with the relationship between the geometry of the structure and its load carrying capacity.

At the Faculty of Architecture, CTU in Prague, current courses of theoretical mechanics (Statics I and Statics II) are followed by courses of Loadbearing Structures.

Statics I focuses on establishing internal forces at statically determinate structures and an area moment of inertia. Statics II introduces the basics of elasticity and strength – simple examples of elasticity, combination of stress on rod and shear and bending moments. An explanation of Mohr's analogy, Euler's formula, representative cases of elasticity, fixed beams and moments on load-bearing reinforced boards is given. The foundation in statics is followed by a 3-term course in Loadbearing Structures which introduces the elements of designing loadbearing structures – their space arrangement and dimensions according to material, such as masonry, reinforced concrete, steel and timber, all according to EuroCodes.

Courses of theoretical mechanics should be complemented by Structural Design subject based on graphic statics even before teaching Loadbearing Structures. We do believe the students will be able to redintegrate their knowledge of theoretical mechanics and join it easier with subsequent study of Loadbearing Structures.

The Structural Design course is prepared as a combination of several learning methods – structural analysis, laboratory experiments and the interactive design of a virtual computer-aided model. Five types of statically determinate plane structures will be discussed in six seminars. In each seminar, an elementary theory describing principles of static behaviour of the particular structure will be explained. Then the students will build a physical model of the structure supplemented with measuring the internal forces caused by loading of the model. Finally, the students will create an appropriate virtual computer-aided model with loading simulation.

To construct the structures, a teaching-aid will be prepared containing a board for demonstration and a building set suitable for creating the truss structures (rods, joints, tackles) supplemented by nylon cables, weights and force transducers.

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