Teaching Structures to Architects

Share of Structural Engineering in Architectural Curricula
at Selected European Schools of Architecture,

Teaching Methods (Traditional vs. Innovative),

and Case Studies
from the Selected European and American Schools of Architecture

Dissertation

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ABSTRACT

The study is devoted to **architectural structural education**.

Views on the problematics are shortly described here from the 50s of the 20th century (Larrick, Salvadori, Kamphoefner, Severud) until nowadays.

The main objective of the study is to **assess the importance of Structural Engineering** (SE) subjects **in architectural curricula**, to **compare and to evaluate** various **teaching approaches** ("traditional" behaviorist vs. constructivist) with the **focus on monitoring the "innovative" ways** (working with models, employing graphic statics methods, utilising computer software). The following methods of applied research have been used: comparison, observation, analysis and sociological research.

Quantitative analysis of % share of SE in architectural curricula has been conducted on the sample of 27 selected leading European English and German speaking universities showing that the **share of SE** varies considerably **(5-42% in bachelor** and **0-45% in master)**. **German speaking** and the **top rated UK** universities **tend to have a higher than average share** (**SE in bachelor: cca 35% for leading British and AE combined courses, 10-15% for most English-speaking, 15-25% for German speaking, SE in master: up to 5%, when further specialisation** in SE, it **boosts** share of SE subjects **to 10-45%)**. In this context, an **8.33% share of SE in bachelor studies at CTU seems to be underrepresented**.

I have also looked into the ways of teaching as a part of the qualitative research, coming to a conclusion that **constructivist methods are beneficial** for architecture students accustomed to learn in visual, creative way, however to base the tuition on hands-on experiments solely would not be appropriate as the **primary "technical base" is in my opinion best received frontally** in order to equip students with the complex synoptic view on the problematics. T**eaching approaches** have been sorted into four main groups (Detailed Scientific/Technical/Anglo-Saxon Attitude (1A), More practically oriented Scientific/Technical/Anglo-Saxon Attitude (1B), Graphic Statics based Attitude (G2), Attitude based on the Historical development of Structural Mechanics (G3)), and **submitted to the evalution**, the results of which lead to recommending the Detailed Scientific/Technical/Anglo-Saxon Attitude as the most appropriate for the architectural structural tuition at the Faculty of Architecture, CTU Prague, though imploring more constructivist activities has been suggested.

key words: structural, architectural, education, teaching, innovative

ABSTRAKT

Studie se zabývá **výukou statiky a souvisejích předmětů na fakultách architektury**.
Názory na tuto problematiku jsou zde stručně popsány od období od 50. let 20. století (Larrick, Salvadori, Kamphoefner, Severud) až do současné doby.
Hlavními cíli práce je **stanovení významu statiky a souvisejích předmětů nosných konstrukcí (SE) v architektonickém kurikulu**, **porovnání a zhodnocení různých učebních přístupů** ("tradičních" vs. konstruktivistických) se zaměřením na "**inovativní**" způsoby (práce s modely, použití metod grafické statiky, implementace počítačového software). Pro aplikovaný výzkum byly použity následují metody: komparace, pozorování (observace), analýza a sociologický výzkum.
Kvantitativní analýza zkoumající **procentuální podíl SE** předmětů v architektonickém kurikulu provedená na vybraném vzorku 27 evropských anglicky a německy vyučujích univerzit ukázala, že podíl SE vykazuje výrazný rozptyl (5-42% pro bakalářské studium a 0-45% pro magisterské). Německé a přední anglické univerzity vykazují obecně vyšší než průměrné hodnoty (bakalářské: přední britské univerzity a kombinované kurzy (arch. inženýrství) 35%, většina britských univerzit 10-15%, německé univerzity 15-25%; magisterské: do 5%, podíl roste při specializaci na statiku na10-45%). V tomto kontextu se jeví podíl 8,33% SE v kurikulu, který vykazuje FA ČVUT pro bakalářské kurzy, jako relativně nízký. V rámci **kvalitativního** výzkumu jsem se zabývala také metodami výuky.
Zde jsem vyhodnotila **konstruktivistický přístup jako vhodnější pro studenty architektury** predisponované učiti se na základě vizuálních vjemů a kreativního založení, ale zároveň jsem dospěla k závěru, že založení výuky statiky pouze na názorných demonstracích není vhodné z toho důvodu, že **primární základna technických znalostí** by měla být studentům zprostředkována **frontálním výkladem** za účelem poskytnutí komplexního přehledného zpracování problematiky. Učební přístupy byly dále rozděleny do čtyř hlavních skupin (1A. Detailní vědecko/technický anglosaský, 1B. Praktický vědecko/technický anglosaský, 2. Založený na principech grafické statiky, 3. Založený na historickém vývoji mechaniky), které byly podrobeny evaluaci. Výsledkem evaluace, do níž byla zahrnuta i specika FA ČVUT v Praze, je doporučení nejvhodnějšího způsobu výuky statiky a nosných konstrukcí. Tím je skupina 1A. Detailní vědecko/technický učební přístup. Zároveň je doporučeno zařadit do výuky více konstruktivistických metod.

Klíčová slova: strukturální, architektonický, výuka, učení, inovativní

DECLARATION

I declare that the thesis has been composed by myself, and that the work has not been submitted for any other degree or professional qualification.

I confirm that I have referenced all the sources throughout the thesis as appropriate, and listed them at the end.

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NOTE abbreviation **"SE"** is used throughout the study for **Structural Engineering**

Fig.0 photo from structural workshop at ABK Stuttgart, Germany

"Understanding engineering behaviour is a bit like learning to ride a bike: intimidating beforehand, but exhilarating in practice. Whether it's force flow, energy transfer or dynamics, I'd like students not to feel intimidated by the apparent complexities but excited by all of the opportunities that engineering offers."

Dr Gregory Charles Quinn

Major Discipline Coordinator for Architectural Engineering

Swinburne University of Technology, Melbourne, Australia

CONTENTS

A INTRODUCTION

Problem statement

The candidate's study has been initiated by the Department of Load-Bearing Structures at the Faculty of Architecture, Czech Technical University (CTU) in Prague, where the lectures on Structural Engineering are being regularly revised and updated.

CTU in Prague is one of the biggest and oldest technical universities in Europe, and according to the 2020 QS World University Rankings[1], out of 1604 universities worldwide it currently occupies 432nd place globally, and 9th in the Emerging Europe and Central Asia Region.[2]

During the last twenty years, number of universities and their faculties offering architectural studies in the Czech Republic has risen significantly, which brought almost tenfold increase of architectural students. At the present time, there are two main trends in architectural education: technical faculties with newly established architectural study programmes (often offering cross-listed courses, e.g. Architecture and Civil Engineering) put the emphasis on technical subjects, whilst traditional schools of architecture have the tendency to simplify them in order to comply with the lower standard of technical knowledge of incoming students[3].

Another aspect of the contemporary higher education is the presence of a “highschool” attitude in some of the university's courses. This means the emphasis is put on a routine practice subsequently leading to the lack of space for a classic seminar, which would improve a critical / contextual thinking. In later stages it can bring students’ inability to accomplish classical analysis; they mainly „copy the facts“ instead of seeing interconnections, and confronting different views on a problem, which would resume in a valid scientific conclusions[4].

In order not to compromise the level of knowledge graduates should display at the end of their studies, whilst taking into account above mentioned lower initial familiarity with the technical background, this study assesses a suitability of various pedagogical attitudes, and investigates some additional activities (already successfully applied at some other

[1] an annual publication of university rankings by Quacquarelli Symonds (QS). The QS system comprises the global overall and subject rankings alongside five independent regional tables and is viewed as one of the three most-widely read university ranking in the world; source: Wiki commons
[2] source: CTU's website
[3] POSPISIL, VAVRUSKOVA, VERTATOVA (2015)
[4] an opinion of prof. Semrad, (MIAS, CTU in Prague); further supported by other CTU's pedagogues e.g. Mgr. Vymetalova or RNDr. Hudecek

universities), which would further support the comprehension of the structural curriculum and enhance the learning process.

Main objectives

The main objective of the study is to **analyze the importance of Structural Engineering** lessons in architectural education of selected Czech and other European (German and English speaking) technical universities (by comparing a share of Structural Engineering subjects in their curricula together with a detailed analysis of its contents), to **monitor innovative teaching methods** (including an assessment of a newly introduced pilot seminar on Visual Statics at the CTU in Prague), and to **discuss suitable forms of lecturing Structural Engineering**. The study is further accompanied by examples from the selected U.S. and world universities.

Strategic target of the research is **to compare ways of teaching Structural Engineering subjects**, which further results in the necessity of collecting, analyzing and assessing comparable data concerning Structural Engineering tuition at selected European / world universities with the potential of applying them into the education process at CTU. This strategic target is further divided into **tactical targets** as follows:

1. **source research of scientific journal papers, conference papers, etc**. covering the subject
2. **quantitative comparison of teaching Structural Engineering** – share of Structural Engineering in curricula of selected universities (formulating and testing hypotheses)
3. **qualitative comparison of teaching Structural Engineering** – detailed analysis of the curriculum structure at some top universities (Case studies), content of selected courses (including analysis of textbooks where available) and teaching methods (focus on the innovative teaching methods)
4. **sociological research** in the form of Structured Interview
5**. experimental lessons** on Structural Engineering education to architects
6. **data evaluation** and synthetic phase of the research

Expected contribution towards the problematics

The main purpose of the study is to provide a basis for potential updates of structural courses at the Faculty of Architecture, Czech Technical University in Prague. The study follows two main areas of interest: the actual amount of structural courses within architectural curricula (that to my knowledge have not been investigated so far), and their content (with special interest towards experiences concerning implementing "innovative" methods and approaches), further complemented by looking at other related curricular or extra-curricular activities. An attachment describing various structural teaching experiences from around the world has been compiled from conferences' papers by the candidate in order to further illustrate the problematics. I am not aware of any similar compilation, therefore I think it might provide an interesting source of information for pedagogues.

Formal structure of the dissertation

The dissertation comprises of seven parts:

A **Formal introduction** outlining the **main objectives**, **expected contribution** towards the problematics, describing **methodology, initial approach**, providing **comparison to methodologies used** in relevant works, and depicting the process of **hypotheses formulation** (incl. their overview), together with listing the **sources** used for the research

B **Overview of the Supporting analytical part**, which is represented by the G1 part containing **Literature review** conclusion, **Higher education didactics** conclusion, Case studies summary and **Case studies conclusion**

C **Analytical-synthetic part** devoted to the research in the field of SE in architectural curricula: **Quantitative research** (percentual share of SE subjects in study plans), and **Qualitative research** (overall teaching approaches, practiced teaching methods (traditional vs. innovative) and their forms), **detailed description of hypotheses forming** and their **verification**

D **Synthetic part** introducing the **grouping of the schools from the sample** according to the conceptual approach towards teaching SE subjects (**primary grouping**), and according to the selected initiatives applied in SE tuition (**secondary grouping**), and further consisting of **critical evaluation of the approaches and initiatives** according to the selected criteria, **discussion on the teaching approaches** from the pedagogic point of view, and **recommendations** for the tuition at the Faculty of Architecture, CTU Prague

E **Summary and Conclusion**

F **Bibliography**

G **Appendices** In this section, following subchapters are further distinguished:

G1 representing the **Supporting analytical part** consisting of the Literature Review Summary (existing opinions on structural architectural are briefly discussed here), **Higher education didactics** (providing basic classification of teaching approaches, methods and forms), and the **Case studies** that have been conducted by the candidate on the sample of eleven selected European German and English speaking universities broadenet by the analysis of MIT Boston, USA, pioneer institution in the graphostatic approach.
G2 informing on selected interesting activities in architectural structural curricula as described in the conferences papers that the candidate analysed, and
G3 devoted to the historic-logical teaching approach promoted by K.E.Kurrer.

Approach and methodology

Methodology of previous related works

As a starting point, **Robert Seegy's** study ***Contribution to Didactics in the field of SE for Architectural Students***[5][6] was analysed for the research. The aim of their project was to develop a course, which would **present traditional SE** material to students **more simply and clearly**, with the emphasis on training them to **design the structure creatively**.
Seegy's approach represents **applied research** (for practical use **-** lecturing SE to architectural students at University of Stuttgart, Germany), employing following methods: **qualitative analysis** and **observation**. Then current situation was analysed and described at the beginning

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[5] SEEGY (1977), original title in German: ***Beitrag zur Didaktik – Auf dem Gebiet der Tragwerkslehre fur Architekturstudenten***
Prof.Dr. **Robert Seegy** is currently a member of staff at the Technische Hochschule Nurnberg, Germany

[6] Seegy's dissertation represents the third part of a research project on teaching structural engineering to architects, which was initiated by Prof Dr Ing Kurt Siegel at the University of Stuttgart, Germany. It was funded by Volkswagenwerk Foundation.
During the first phase, which took the place between 1969-1970 and was directed by Dipl Ing Ayla Neusel (supervised by Prof Siegel), following topics were covered: introduction to SE, truss, arch, rope and graphic statics.
Under the leadership of Prof Siegel in the second phase between the years 1971-1973, further areas were added: single span beams, single span beams with cantilever arm, tension and compression in bars, continuous beams and frames. By evaluating numerous test runs (with the help of students), a learning programme featuring audio-visual tutorials accompanied by **workbooks** was developed. Students practiced tasks featuring statics fundamentals and simple static systems.
In the third part of the project combination of elements and structures with special consideration of the spatial rigidity were covered. Around that time the importance of a creative approach materialised and was looked into in more detail leading to developing creativity promoting methodical didactic concept described by Seegy. Learning and thinking psychological aspects were overseen by Prof Dr Dieter Luttge, teaching experiences by Prof Dr Ing Nikola Dimitrov.

of Seegy's thesis, followed by a discussion and highlighting the problems of then commonly practiced ways of teaching SE to architects. In accordance with formulated **theses** (1. training in systematical problem solving is needed, 2. creative thinking process expands individual capacity for solutions, 3. knowledge transfer / thinking materials should be easily available, 4. selection and evaluation of the proposed solutions only fruitful when based on logical thinking, 5. programmability: yes/no strategies not suitable for creative skills), author's attention was predominantly devoted to the analysis of thinking processes (discursive vertical thinking, multiple thinking and creative thinking[7]), succeeded by an examination of the problem solution processes, of the teaching concept (its phases and recommended principles, training, motivation, stimulation, selection and evaluation, knowledge transfer and programmability). This theoretical part consists of approximately 30 pages.

The **practical part** of the Seegy's dissertation (containing cca 130 pages) is represented in the form of a texbbook, depicting the suggested didactic approach.

Unfortunately, there is no sample of an accompanying mentioned workbook present in the text, but an example of some pages from previous stages of project can be found in appendices.

Equally disappointing is also an absence of some evaluation/reflexion from the actual running of the courses, but I can assume it as successful because of its gradual expansion within several years.

Pilot search monitoring the area of teaching Structural Engineering to architects was conducted in 2013 in cooperation with ***National Library of Technology in Prague*** as a second step. Free foreign digital libraries were searched as well as database SCIRIUS, but unfortunately, ***no relevant research*** was found for phrase "structural" and "construction" in combination with "teaching", "education", "learning", "research" or "methodology". There were some methodologies available in connection with "civil engineering" (though mainly at licensed sources), evaluated as of limited use for the research focusing on architectural courses (as I find architectural students less technically orientated in comparison to civil engineering students and therefore I regard these as not fully appropriate for them).

My attention therefore turned towards the social networking sites for scientists and researchers such as ***Research Gate*** or ***Google Scholar***, which proved resourceful. The topic of the teaching SE to architecture students is covered predominantly in the form of scientific articles (mainly from various topical conferences), a list of which is arranged alphabetically according to their authors in bibliography[8]. Particular texts are discussed throughout the

[7] Seegy quotes Oerter (1971) and Ulmann (1968)

[8] conference papers bibliography pp. 161-165

whole text according to their relevance.
As far as the methodological approach of authors of scientific articles is concerned, it belongs to the category of **applied research**. The authors typically describe their "innovative" didactic approaches, using the following scientific methods: **observation**, **analysis** (mostly qualitative) and **comparison**. The characteristic structure of such article begins with a description of a current situation, citing pros vs cons of methods and ways of teaching at the particular university, usually highlighting the cons. Subsequently, a research into present and past pedagogical attitudes is presented (usually suported by various psychological studies or opinions), leading to formulating the statements of more general character. Introduction of the new, innovative or improved method is then introduced, described, discussed, explained and evaluated.

Furthermore, I would like to mention two other researchers, whose dissertations followed the problem of teaching SE to architects, and describe their methodological approaches.

Claudia Pedron is the author of ***An Innovative Tool for Teaching Structural Analysis and Design***[9]. In her work, she adressed the question of how the use of ICT could be used to help teaching and learning SE within architectural courses, stressing the necessity of proper modelling of the real-life structures in the first place, closely followed by the need for correct interpretation/extraction of the computed results. In her dissertation, she presents an undergraduate architectural students-friendly teaching and learning platform ***Easy Statics*** ("virtual structural laboratory") she has developed and which has been run at ETH Zurich.
The introductory part of the dissertation (approx. 30 pages) consists of chapters devoted to a brief history of structural analysis[10], classification of the teaching attitudes[11] containing a short discussion on two general didactic methods - teacher-centered vs. student-centered (highlighting disadvantages of "traditional" ways), and an overview on the use of technologies in science education. The core part of the work (approx. 90 pages excl. appendices) is devoted to the description of Easy Statics program. Academic experience is present towards the end of the work as well as general assessment and possible future developments.
Pedron's dissertation is another example of an **applied research** (practical use, for architectural students at ETH Zurich) , using following methods: **analysis, comparison and observation.**

[9] PEDRON (2006)
[10] Pedron uses KURRER (2002) as a source
[11] Pedron uses CONWAY (1997) as a source: CONWAY, J.: ***Educational technology's effect on instruction***, 1997

The second **applied research** was conducted by **Gbenga Martins Alalade**[12] who focused on "rethinking" approaches to teaching and learning SE in architectural schools. The situation was investigated at four universities in Southwest, Nigeria, and random sampling techniques were used on 288 students by the means of **structured questionnaire** and **guided interview**. **Content analysis** was then applied to the collected data. His chosen objectives were mainly to assess the curriculum, to examine the approaches to the teaching and students' perception of these approaches, to investigate students' personality characteristics in relation to learning styles and to assess the degree of ICT use. Further methods applied in this research are represented by **observation** and **comparison, analysed and discussed** were also pedagogical approaches (traditional vs. alternative), learning styles and learning theories (constructivism, Kolbs Experimental Learning Theory, technology-Enabled Active Learning).
Dr Alalade concludes that an emphasis on design studio-oriented approach and a wider adoption of digital technologies are the key factors leading to the overall improvement of the current situation. Furthermore, he promotes visual-spatial thinking and visual communication strategies to currently used mathematical thinking and numeric communication strategies.

Formulation of hypotheses

This research belongs to the category of **applied research** (practical use, teaching SE to architects at the Faculty of Architecture, CTU).

Formulating hypotheses was a gradual process described bellow.
At this place, **hypotheses** are listed in the form of **general preview** only[13].
Their gradual verification is described in detail in the analytical-synthetic part of the research.

For the first steps a detailed look at the curriculum of architectural programmes at CTU in Prague (architectural design vs. architectural engineering courses), closely followed by a corresponding action for four chosen representatives of European German and English speaking universities, has been chosen (an Introductory study). For this purpose, methodological approaches in the form of **quantitative analysis, comparison and observation** were used.
Study programmes were compared for the actual percentual content of SE subjects within for the bachelor and the master courses, and the first two hypotheses have been formulated[14]:

[12] ALALADE (2017)
[13] see analytical-synthetic part pp. 44- 91 for detailed info and discussion (verifiing/ refuting hypotheses)
[14] H1 and H2 hypotheses details: see p. 49, pp.55-56, pp.87-88

Hypothesis H1:

The percentual share of SE subjects in bachelor architectural curricula of German universities is higher compared to other European universities.

Hypothesis H2:

The share of Structural Engineering subjects at Faculty of Architecture at CTU in Prague is underrepresented in context to other selected European English and German universities.

For a verification/refuting of H1 and H2, **quantitative analysis, comparison and observation** were chosen. Hypotheses were tested in the second partial research working with the enlargened sample of 27 selected German (15) and English (12) speaking universities. In relation to this analysis (Follow-up study), two further hypotheses were formulated[15]:

Hypothesis H3:

Volume of Structural Engineering subjects in architectural curricula is on comparable levels for selected major Czech (and potentially Slovak – because of joint history as Czechoslovakia in the years 1918-1992) technical universities.

Hypothesis H4:

Having allocated more time to Structural Engineering in their bachelor architectural curricula, students at German and the top rated British universities are taught wider range of SE topics than students at other selected European faculties of architecture.

Hypothesis H3 was tested in a Supplementary study[16], hypothesis H4 in an Additional supplementary study[17] and a Pilot study on aims and contents of SE courses[18].

Hypothesis H3 and H4 were investigated with the help of **quantitative analysis, comparison and observation**.

Simultaneously, several partial studies into the problematics devoted to **qualitative apects** of teaching SE to architectural students were conducted using following methodological approaches: **qualitative analysis, observation, sociological research** and **comparison**.

Within the scope of these studies, a new hypothesis H5 emerged:

[15] for H3 and H4 formulation see p.56

[16] Supplementary quantitative study, pp.57-59

[17] Additional suplementary quantitative study, pp.60-63

[18] Pilot study on aims and content of SE courses, pp.80-86

Hypothesis H5:

Innovative teaching methods are more appropriate for teaching SE subjects to architectural students than traditional frontal methods.

Overall summary of methodology applied in the research incl. activity description

Applied research is used (for practical use – teaching Structural Engineering at Faculty of Architecture at CTU in Prague, Czech Republic) with the following methods involved:

Comparison

- spreadsheet applications (percentage share of Structural Engineering in curricula, number of ECTS credits in curricula)
- verbal comparison of content of Structural Engineering courses (e.g. topics covered by particular course/curriculum)

Observation (Empirical Explanation Method)

- finding out the types of methods of teaching at selected universities (e.g. "frontal", "learning by doing"- description, representation in courses)

Analysis (Empirical Common Theoretical Method)

- sorting and classifying input data (spreadsheets, charts…)
- verbal comment (advantages vs. disadvantages of particular methods…)
- assessing the outputs of the Structured Interviews
- formulating and testing (verification vs. falsification) hypotheses

Sociological research

- conducting a Structured interview

Comparison to the methodology of existing relevant works

As can be seen from the description of particular attitudes of previous researchers, there is a unilateral understanding on the importance to **combine several techniques** in order to produce an indepentent, balanced research. Relevant works naturally display certain variety in combination and level of use of particular methods according to the researchers' needs arising from their specific focuses. The method of **analysis** is represented in all related existing works I came across as breaking the complex topic into smaller parts in order to gain better understanding of it is a highly effective procedure. For the purposes of the research, I have adopted both qualitative and quantitative version, **qualitative** for an assessment of particular teaching methods or for contents of selected courses, **quantitative** for "countable" features such as the amount of lessons of certain type in overall curriculum. To compare my approach with the related existing works on the topic, with the exception of Alalade's statistical survey, I have not came accross the quantitative analysis as such. The reason might be due to the focusing on the process of teaching itself, however in my opinion, it represents an important relevant parameter, whose inclusion helps to create more complex view on the problematics, therefore I have included it in the research in comparable volumes to research qualitative.

The use of analysis is closely related to the use of **observation**, which usually predecedes the actual analysis. I have used observation mainly for listing the teaching methods and for an assessment of a pilot virtual statics course. Observation is in various forms present in all related works studied.

Comparison is reflexed in related works in two main forms: comparing the original ways of teaching to the newly applied ones at particular schools (usually preceded by some referrals to educational theories), and comparing the schools among themselves. As the first form prevails in the most of articles I have studied, I came to a conclusion that it might be benefitial for parties interested in this matter to have a more detailed comparison at hand.

Statistical data collection is generally less frequent as it requires meticulous preparation (precise specification and a clear idea of targetted information), takes more time to gather, and is generally more laborious to evaluate. I see it as more appropriate to use in the advanced stages of a research, therefore it was used only to a limited scale (number SE lessons in architectural curriculum within particular course and school) in this investigation.

Sociological research in the form of a **structured interview** was used in the research as a supplementary method when an opportunity arised in order to generate new ideas for the research and/or to verify/refute working theories on the suitable forms of knowledge transfer (e.g. asking students with experiences from both "foreign" and Czech systems to compare, or enquiring with foreign lecturers some details related to their work, though in this area, I was actually quite limited by the willingness of other parts to participate). I can see an opportunity of further development in this area by actively engaging exchanging students from the Faculty of Architecture of CTU in the future in the form of gathering various materials and sharing their experience more widely.

Sources, related work & existing knowledge

Teaching statics and related subjects to architectural students problematics can be researched from **various sources** as follows: particular schools' websites and course catalogues, educational websites (both informative and interactive), websites of related institutions, universities rankings websites, SE textbooks, pedagogy textbooks, and related conference papers.

Websites of related institutions

- European Network of Heads of School of Architecture – ENHSA[19]
- European Society for Engineering Education – SEFI [20]
- Journal of Professional Issues in Engineering Education and Practice[21]
- European Journal of Engineering Education[22]
- Association of Collegiate Schools of Architecture - ACSA[23]
- International Association for Shell and Spatial Structures - IASS[24]
- Architectural Research Centers Consortium - ARCC

Some of the above listed institutions organize **regular conferences or events**, which let the professionals exchange their ideas (e.g. 2018 IASS International Conference: "**Creativity in Structural Design**"[25] incl. also sections: Waclaw Zalewski Memorial, Graphic Statics, Education of Architecture and Technology, or currently planned IASS 2019 International Conference: "**FORM and FORCE**"[26]). The full list of IASS events since 1989 is available online.[27]. Another example is ACSA's recent conference "**Less Talk/ More Action:**

[19] http://www.enhsa.net
[20] https://www.sefi.be
[21] published quarterly, edited by Shane Brown, PhD, P.E., F.ASCE, Oregon State University
[22] https://www.tandfonline.com/toc/ceee20/current?nav=tocList, visited July 2019.

[23] **Association of Collegiate Schools of Architecture (ACSA)**: founded 1912 (10 members); nonprofit association; nowadays over 200 member schools in several categories in the USA and Canada (over 5,000 architecture faculties are represented), and in addition, over 300 supporting members (architecture firms, product associations, individuals); source: ACSA's website, visited July 2019.

[24] **International Association for Shell and Spatial Structures** (IASS): founded by Eduardo Torroja in 1959, non-profit organisation; interchange of ideas among all those interested in lightweight structural systems such as lattice, tension, membrane, and shell structures, in particular architects, engineers, builders and academics; annual symposia; source: IASS's website, visited July 2019.

[25] July 2018, MIT Boston, Cambridge, Massachusetts, USA
[26] October 2019, Barcelona, Spain
[27] https://iass-structures.org/Annual-Symposia, visited July 2019.

Conscious Shifts in Architectural Education"[28]. To name other educational conferences: ICQH (International Conference on Quality in Higher Education), IETC (International Educational Technology Conference), IDEC (International Distance Educational Conference), END (International Confernce on education and New Developments). And finally, the samples of events focused on ICT use in connection to architecture: ROB/ARCH[29], eCAADe[30], AAG[31], FABRICATE.

An important landmark for European higher education was **The Bologna Declaration**[32] in line with which the curricula are structured.
Although one of its main goals was to minimize the differences of particular national educational systems, **Tomovic** points out towards the Implementation report[33] that states that the actual pace and style of these reforms is different in each country and does not actually lead to their leveling.

Characteristic features of our era are globalisation, social transformations and ongoing technological innovations. The challenge universities face in training students is to prepare them to meet the demands of the market and equip them with skills required for successful integration into nowadays workforce (Ortiz et al., 2014).
Expert groups consisting of specialists from Member States, EFTA/EEA countries, associated countries and European-level associations have been established with the main objectives to identify and define the new skills - **Key Competencies**, and their integration into curricula (Tapio, 2004), (Hucinova, 2004).

Universities ranking websites

Following independent university rankings were used for the selection of universities:
QS World[34], THE World[35], The Complete University Guide[36], The Guardian League Tables, CHE Ranking[37], URAP[38] Ranking, Baunetz[39] Ranking.

[28] September 2019, Stanford, USA
[29] Robotic Fabrication in Architecture; since 2012
[30] Education and Research in Computer Aided Architectural Design in Europe
[31] Advances in Architectural Geometry
[32] a major reform signed by the education ministers from 29 European countries in 1999
[33] ***The European Higher Education Area in 2015: Bologna Process Implementation Report***;
available on:
https://eacea.ec.europa.eu/sites/eaceasite/files/european_higher_education_area_bologna_process_implementation_report.pdf visited July 2019

[34] **QS World University Rankings by Subjects**; each of the subject rankings is compiled using four sources: QS's global surveys of academics and employers (used to assess institutions' internal reputation in each subject), research citations per paper, h-index (sourced from Elsevier's Scopus database); see also fn.1, p.18

Schools websites and course catalogues

The websites of particular schools selected for the research were subjected to a detailed analysis. The websites' contents differ to a great extent, therefore direct requests were made where possible in order to further broaden are sources.

Educational websites

We can further differentiate an **informative** (e.g. Seeing and Touching Structural Concepts (University of Manchester)) **vs.** an **interactive conception** (e.g. eQuilibrium (ETH), Active Statics (MIT), Virtual Laboratory (CTU)) of the pages. Particular websites and their features are described and placed within the study in relation to their affiliations.

Textbooks and course syllabi & presentations

Textbooks from the two main fields of interest associated with the research were submitted to the initial examination.

On the SE topics, the list of the fundamental works can be further categorised according to the their main focus: statics textbooks (***Grundlagen der Tragwerkslehre***, ***Technische Mechanik***), general structural textbooks - some of which devote a substantial part to the material solutions from structural point of view (Ching: ***Building Construction Illustrated*** (2014), Salvadori: ***Structure in Architecture***, Silver & Lean & Evans: ***Structural Engineering for Architects***, Schodek & Bechthold: ***Structures***, Block & Gengnagel & Peters: ***Faustformel Tragwerksentwurf***, ***Prof. Schwartz's online textbooks and course syllabi***, Deplazes: ***Constructing Architecture: Materials, Processes and Structures*** (2008), Seward: ***Understanding Structures: Analysis, Materials and Design***), visually focused textbooks (Bizley: ***Architecture in Detail I+II*** (2007) , specific design areas textbooks (***Holzbau Atlas (Timber Construction Manual*** in English version***)***, ***Stahlbau Atlas***, ***Beton Atlas, Facade Manual***), learning by doing textbooks (Kuenzle: ***Demonstrationen an Tragwerkmodellen***

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[35] **Times Higher Education World University Rankings** is the global university performance table using 13 fully calibrated performance indicators, first published in 2004

[36] Three national rankings of universities in the UK are published annually by **The Complete University guide**, **The Guardian** and jointly by **The Times and The Sunday Times**. Rankings have also been produced in the past by The Daily telegraph and Financial Times; The Complete University Guide is compiled by Mayfield University Consultants; ranking uses 10 criteria; first published in 2007

[37] **The CHE** (Center for Higher Education) **University Ranking** is the most comprehensive and detailed ranking of German universities and colleges.

[38] University Ranking by Academic Performance

[39] German ranking in the professional field

(2005), Sabnis & Harris: ***Structural Modeling and Experimental Techniques*** (1983)), graphic statics as a teaching method textbooks (Allen & Zalewski: ***Shaping Structures Statics*** (1998), ***Form and Forces*** (2009), Prakash: ***Graphical Methods in structural Analysis*** (1997), graphic statics in general works (***Prof. Simek's Lectures on Graphic Statics*** (1949)), building standards in particular countries guides (***Architect's Pocket Book***, ***Structural Engineer's Pocket Book***, ***Neufert***), and practical design instructional booklets (***Tabellen zur Tragwerkslehre***, Chudley & Greeno: ***Building Construction Handbook*** (2014), Ochshorn: ***Structural Elements for Architects and Builders***).
Some of the above listed books could actually fit into more categories (e.g. some of the general structures books show highly visual content aiming at architectural students).

As far as the pedagogy is concerned, the main source for our research provided following books: Petty: ***Teaching Today*** (1998), Rohlikova & Vejvodova: ***Teaching Methods at the University***[40] (2012), Zormanova: ***Teaching Methods in Pedagogy***[41] (2012), Kasikova: ***Cooperative Learning, Cooperative School***[42] (2010); as well as pedagogical parts of dissertations of Pedron[43] (2006) and Alalade[44] (2017), and innumerable scientific papers devoted to various aspects of the problematics. Further textbooks (including on the topic of the key competencies) are listed in Literature section.

Conference papers, professional journals

A relatively large volume of **scientific papers** associated with the topic suggests its actuality (especially in the recent years) as well as the need to contribute to the discussion on the position of SE within architectural curricula, and on the most suitable ways of teaching it. Their content varies from expressing an opinion on the **relation between an architecture and a structure**, giving a detailed **description of various methods of teaching SE at particular schools** and concentrating on the **implementation of various softwares** to the views on the process of teaching structures to architects in general. An overview of papers and articles used for this research can be found in the particular section of the bibliography.[45]

[40] original Czech title: Vyucovaci metody na vysoke skole
[41] original Czech title: Vyukove metody v pedagogice
[42] original Czech title: Kooperativni uceni, kooperativni skola
[43] PEDRON (2006), dissertation, see p.23
[44] ALALADE (2017, dissertation, see pp.23-24
[45] conference papers bibliography pp.161-165

B SUPPORTING ANALYTICAL PART - OVERVIEW

Literature review conclusion

The basic set up of architectural curricula of particular schools is best to find at universities's websites, and check with course catalogues. There has always been considerable differencies as far as the level of information is concerned, and due to the growing trend to move some data to schools's password-protected intranets, some of the information in the study comes from the initial phase of the research.

On the actual ways of teaching structural engineering and related subjects to architects, information can be predominantly obtained from conference papers (though the fact that people are most probably not going to inform the scientific community that they are "teaching the same way for many years and are happy about that"- however controversial to the natural human trait of curiosity or to the desire to evolve it might sound - should be borne in mind); to the methods of teaching in general, separate chapter is dedicated in the Supporting analytical part/ Higher Education Didactics[46], and an overview of the textbooks that are being used at particular schools resp. for particular courses (which can also give us a rough idea about the overall approach at certain environment), can be found in the Supporting analytical part/ Case studies[47].

The scientific articles, that have been subjected to the analysis, revolve around several principal questions bellow (followed with suggestions that have been made):

- the importance of structural courses within the architectural curricula (resp. the importance of structural literacy), on which (with the exception of Prof.Ochshorn's interesting opinion)[48] consensus was reached as being significant for architects
- implementation and extent of scientific approach within the courses (mathematical formulas, scientific character of explanation...) was not completely excluded however the situation seems to be more in the favour of simplification
- the broad topic discussion on the actual form of structural courses as such has turned out as repeated demand for linking the theory with praxis i.e. mainly by joining structures with studio as well as incorporating active exploratory activities within (work with small-scale structural models)
- use of the ICTs has been unanimously appraised (though with certain reservations) ; the main focus is on the possibilities of virtual reality for education

[46] G1.2 part in Appendix, Higher education didactics, pp. 202-236

[47] G1.3 part in Appendix, Case studies, pp. 237-335

[48] OCHSHORN (1991)

Higher education didactics conclusion

As mentioned by several pedagogy theorists (e.g. Kasikova, Manak, Rohlikova, Skalkova, Svec, Vejvodova, Zormanova), there is a current trend in the higher education didactics to move away from the "traditional" transmissive (instruction based) methods, and to incline towards "modern" innovation (constructivism based) methods and towards the more complex forms of teaching.

The process is supported by several psychological expertises, has its roots in ancient times (method of dialogue or didactic games), and follows the logic of the historical development of teaching methods, where the use of memory-based attitudes evoked reform pedagogy theories (e.g. Comenius in the 17th century or John Dewey in the 20th century).

Jean Piaget asks if we should "educate the children and people who are only able to learn what is already known and repeat it?...or if the aim of education is to form a creative innovative spirit allowing discover and conceive new things throughout the whole life?". Zormanova and Pecina (2009) refer to Okon's (1966) list of typical features of traditional teaching (dominant role of teacher, who concentrates on curriculum, predominance of interpretation method, passive students), inform of a very intense critique of traditional attitudes at the beginning of the 20th century (Dewey, Steiner, Montessori, Pettersen, Parkhurst, Freinet), but also discuss low level of effectiveness of constructivist methods and specify cases, when traditional methods would be more appropriate (e.g. to conwey a difficult to understand complex substance requiring broader knowledge). Skalkova (1971) brands teaching based on reproducting ready knowledge as insufficient for its lack to prepare students for the real life problems; nevertheless she also says (2004) that rejecting traditional and wellcome modern pedagogy would represent considerable simplification. Rohlikova and Vejvodova (2012) also highlight pros and cons of particular attitudes, and cites Tracey (2009), who thinks that overall constructivist concept does not rule out presence of instructional parts within, or Seymour Papert (1996) who says that he "acknowledges both ways, instructional and constructivist, and the right attitude would be to balance those two", which is also my opinion.

Teaching methods as such represent a dynamic element (changes faster than concepts or organisational forms), therefore teachers should choose them carefully, subordinate them to the aim of the course and use them appropriately to maximize their potential.

Case studies summary

Ten European leading architectural schools: five German (**ABK Stuttgart, HCU Hamburg, RWTH Aachen, TU Munich, UDK Berlin**) and five British (**UCL London, University of Bath, University of Cambridge, University of Edinburgh, University of Manchester)** have been chosen together with **ETH Zurich, Switzerland** and **MIT Boston, Cambridge, USA** for a detailed analysis of their study plans in order to establish the importance of structural engineering subjects within the architectural curricula, and to compare their study plans to the one of the **CTU in Prague, Czech Republic**, an initiator of the study.
Further examples describing various interesting approaches towards teaching structures to the future architects can be found in ATT 2 (Case studies from conference papers), and contain contributions e.g. from the USA, Russia, Turkey, China, Canada, Spain, Poland, or Bosna and Herzergovina.

The faculties of architecture from the main sample of 12 universities have been selected for their **consequitive top positions** within several reputable rankings (**e.g. QS World University Rankings**[49]) as well as for displaying the features related to the survey (e.g. an **innovative approach towards teaching structures, an interesting related activities or a thought-provoking view on the problematics**).
MIT Boston and ETH Zurich are leaders in developing and running **graphic-statics based learning concepts** as well as promoters of **elaborate hands-on experiments**.
Most of the structural tuition takes part within the bachelor phase of architectural studies, therefore the focus is put onto them.

When the **number of students in a yeargroups** from the main sample is compared, it varies greatly. The lowest count (around 40) is typical for MIT Boston or the University of Cambridge, relatively "small" is also a yeargroup at UdK Berlin, which comprises of 50 students. Middle range is represented by e.g. HCU Hamburg with 100 students, comparable to the University of Edinburgh's 120. The universities with the most students in a yeargroup are for example ETH Zurich with or RWTH Aachen, both with the count of 250 students in year 1.
As far as the **graphic statics concept** is concerned, its importance in today's lecturing and appropriatness for predominantly visually perceptive students has been discussed by the

[49] university rankings, p.29

scientific community as referred to in the literature review part,[50] and is mostly positively acknowledged. As referred by Gerhardt et. al (2003), Faisst [51](1975) in his thesis came to a conclusion, that:" studies shown that theories are easily understood and lastingly memorised by students due to the illustrative quality of model experiments".

Graphic statics principles and solutions are (besides ETH and MIT) taught in the second term of Year 1 "Fundamentals of Structures II" course at **RWTH Aachen**[52], implemented in Structural Design modul in the first term of Year 1 at the University of **Cambridge**, UK[53], recommended by Baxter et al.[54] (2015), or mentioned by Causevic et.al. (2014) for their combined use with the numerical methods at the **University of Sarajevo**. Pedro Museros,[55] one of the authors describing the interactive project at the **University Jaume I de Castellon, Spain** (2002)[56] is the author of recently published Vector Mechanics textbook. Graphic statics is taught also at the University of Bath, UK, and is known to students from TUM, Germany.

The activity described by Museros (2002): iterative creation of "optimal" structure using bars and plastic joints whilst using SAP 2000 computer software for structural analysis, is one of the first described examples of combining **learning-by-doing** approach with simultaneous use of the ICT. The use of **structural models** has been promoted for example by Severud (1961), who said, that structural principles "cannot be learned if they are not applied", and actively realised by e.g. Plesums (1974) at the **University of Oregon**, USA, or at the **University of Sydney** as reported by Cowan (1982); the later even inspired topical textbook ***Structural modeling and experimental techniques***.[57] Lonnman[58] (2001) classified the types of models used for structural lessons for architectural students, and accompanied his paper by examples from the **University of Hong Kong in China**, where both physical and virtual models had been used on a regular basis. Very interesting hands-on project is represented by the Bell's and Ti's (2009) "Seeing and touching **Structural Concepts** in Class Teaching"[59] coursework running for several years at the **Manchester University** in the UK. The idea of the project is based on finding structural principles in real-life occurences, some of which

[50] see Literature review summary (chapter G1.1, Appendix, pp.186-201) and related papers: ALLEN, ZALEWSKI (1996, 1997, 1998); GERHARDT, KURRER, PICHLER (2003), BAXTER, JOHNSON, FRALICK (2015); OCHSHORN (2017)

[51] Faisst, K. ***Illustration of support system through models Studies on the learning success***

[52] Dr. Gerhardt received a teaching award by the Fachschaft Architektur in 2012 for the lecture and exercises introducing graphic statics to students at RWTH Aachen

[53] the course leader Dr. Ramage, University of Cambridge's Reader in Architecture and Engineering, has studied architecture at MIT Boston, USA, see also Case study/ University of Cambridge pp. 279-286

[54] taught at the **University of St.Thomas St.Paul MN**, and at the **University of South Carolina, Aiken**.

[55] since 2010 at the Polytechnic University of Valencia

[56] JAUME I University, Castellon, Spain, see p.69 and pp.348-349

[57] Sabnis, Harris: ***Structural modeling and experimental techniques***, 1983

[58] University of Hong Kong, China, see pp.342-343

[59] Structural Concepts at University of Manchester, UK, pp.297-305

were introduced to students, and some of which students were challenged to discover themselves. Accompanying website is of a high didactic value. Yazici team (2013) from the **Istanbul Kultur University**, Turkey describe their experience with learning-by-doing assessment in the form of setting the task to hold an object in the air without a direct support from the underneath[60], and find the activity as a good supplement of their structural courses. Physical modeling has proven popular also at the **Wroclaw Technical University** in Poland, where the team of Ogielski et al. [61](2015) aimed with their activities to improve students' structural intuition; not very often seen was e.g. the use of the soap film to inspire the design of minimal surface structures. A detailed active learning concept has been devised by the team of prof. Buellow from the **Taubman's College of Architecture at the University of Michigan,** USA. A set of easy-to-follow hands-on experiments[62] illustrates following structural principles during the Structures I course: adding forces, moment of force, equilibrium, truss analyses (with the help of graphic method), concept of arches, elasticity, centroid of area and shear stress. Follow-up Structures II course specialised on demonstrating additional structural principles: buckling in columns, deflection in cantilever beams, behaviour of steel beams, flitched beams and continuous beam, as well as combined stress experiment. Soto-Rubio (2017) investigated the use of physical models in teaching structures, and documented several examples from the North American Universities (**California College of the Arts in San Francisco, the University of Michigan, the University of Minnesota, Syracuse University, Montana State University)** as well as a description of students' assignments from his affiliated workplace, **the Faculty of Environmental Design of University of Calgary[63]**. Detailed description of the whole new teaching concept (combining British and German approaches) from the Moscow Architecture School, Russia[64] shows physical modelling complemented with the use of computer software (students observe e.g. deflecting of a simple beam with various cross-sections or building, or build a timber arch bridge, which they load to failure and investigate). **Loading to destroy and observing structural models** within structural courses is taking part also at **TUM, Germany or at the University of Cambridge, UK**. Learning-by-doing concept has a long tradition also at **ETH Zurich**, where **prof. Kuenzle** created a series of demonstrations for the introductory course of structural analysis as described in his textbook[65] and referred to by Pedron (2006) in her thesis. Vrontissi[66] (2018) gives a detailed account of more recent project: "**Constructing**

[60] Istanbul Kultur University, Turkey, see pp.346-347
[61] Wroclaw University of Science and Technology, see pp.355
[62] University of Michigan, USA, see pp.350-351
[63] University of Calgary, Canada, see pp.340-341
[64] Moscow Architecture School, Russia, see pp.352-353
[65] KUENZLE (2005), see p.69 for the description of demonstrations
[66] VRONTISSI et al. (2018), Constructing equilibrium, pp.250-253

Equilibrium", which has been running there since the 2013-2014 term. The task starts with a playful activity asking students to create a composition in equilibrium out of the common household objects chosen from the given catalogue, and then further challenges them to develop its structural principle into a proper structural design.

A subject with the name **Experimental Construction**[67] has been prepared as an introduction into structural studies by the tutors from **HCU Hamburg**, who also organize similar activity for the secondary-school students. During the first term of their bachelor programme students conduct experiments on a small-scale structural models (four hours per week); an experience about which they product an essay at the end of the course. The attendance is compulsory. The variation for secondary-school students is represented by the bridge building workshop, when students get limited amount of material, which they need to use effectively. Gymnasium students are also wellcomed at **RWTH Aachen**, where they can attend selected lectures within the scope of "**Wegweiser Studium**", an interest boosting activity.

An important role of ICT within structural courses is undisputable. Students can take advantage of the **web-based interactive education** such as eQuilibrium (ETH Zurich), or Active Statics (MIT Boston). The CTU Prague has its own interactive GeoGebra based collection of statics problems to explore, which can be accesible by the students in order to observe changing statical behaviour of particular types of structures under different load as well as graphic statics tasks. Students can use various programs for **analysis of the structures** as described e.g. by prof. Chiuini (2006) from the Ball State University, Indiana, USA[68] or by Emami (2016) from the Taubman's College of architecture of the University of Michigan[69]. An illustrative example of implementing ICT into the teaching structures is described in detail by Dr.Hong from Southern Polytechnic State University, in the USA.[70] The most recent feature is represented by the potentials of **Virtual Reality**, as described e.g. by prof.Gengnagel from UdK Berlin.[71]

With the exception of MIT's graphic statics concept, the typical attitude towards the **organisation of structural courses** within the architectural curricula is represented by the introduction of basic static principles in the first term of the first year (resp. in the second term of the first year at CTU Prague or at the University of Edinburgh), when **mechanical terms such as force and moment, equilibrium conditions, static systems, basic multipart**

[67] (Experimentelle Konstruieren), see p. 310
[68] Ball State University, Muncie, Indiana, USA; see pp. 338-339
[69] University of Michigan, USA; see pp.350-351
[70] Kennesaw State University, Georgia, USA; see pp.356-357
[71] UdK Berlin, Germany; see pp.331-335

load-bearing structures, plane trusses, internal forces in beam structures, catenary and line of thrust, resistance moment and moment of inertia, axial and bending stresses, deformations and **stability** are explained, and then followed (in the case of German universities and the CTU) by some forms of pre-dimensioning structural members for particular material variations (masonry, timber, steel, reinforced concrete); the practice also reffered by Chiuini[72] as common at the American universities. In the most cases, there are also moreless simulatneously running courses on Construction, which give the students background for the actual designing. It is not so detailed at the British schools, where more attention is given to the analysis of the structure, and designing the structural part comes only to certain extent in relation to the main project work. The length of statics courses at the British universities varies slightly, being longer and more detailed e.g. at the University of Bath. Great focus to structures is paid at the University of Cambridge, however its structural courses are more essays-oriented, and designing as such takes part mainly in connection to studio work, as is also typical for the Bartlett school of Architecture of UCL London. In the first year of their studies, students typically have around 180 minutes of some form of statics per week (usually 90-minute lecture and 90-minute exercise in small groups, but also e.g. 160 min per week at Edinburgh or 240 min per week at Cambridge), with the length of the school year of 2x14 weeks at most German universities (TUM, HCU, UdK , ABK), 3x8 weeks at Cambridge (with the last term devoted to exams only), 2x12 weeks at the ETH Zurich, where lectures take turns with exercises in 105 minutes slots once a week, and 12 weeks per term at CTU (statics starting later, in the second term). Apart from the first year arrangement, there is no general pattern; statics courses can either continue for the next year or not, and are or not accompanied by the Construction courses. For particular settings see individual cases as described earlier in the Case studies section.

A form of the **exam** also varies from 3-hour long written tests at the ETH Zurich or at the University of Cambridge (where the weight of the coursework represents 40% of the overall mark in year 1, resp. 20% of the mark in the year 2) to no written exam for one of the Technologies course at the University of Edinburgh (where the weights of particular assignments towards the final mark are meticulously planned), or 1-hour test at another Technology course also there. Very detailed "weight" distribution displays also the ABK Stuttgart's marking system, where for example the weight of homework to the final mark of Structural design course is 20%. Self-study requirements for structural courses at particular universities fluctulate between 3-6 hours per week per subject.

[72] CHIUINI (2006); originally quoted by BLACK, DUFF (1994)

Students can participate in the exchange programme **Erasmus,** which gives them an oportunity to study at one of the partner universities. It is either compulsory (UdK Berlin) or voluntary (offered e.g. to students from TUM (during the 3rd year), CTU (during the 4th year), Edinburgh, UCL London or Bath).

The **project or studio work** holds undisputably the key position in the architectural curricula as is clearly seen from the amount of time allocated to it at every school from the sample. A common practice is, that students start with a smaller-scale, more abstract projects at the beginning of the course and work towards more complex exercises at the end of the year and with the progressing years, but for example at the **University of Cambridge** for the last two years, the tutors have decided to run a large scale design from the beginning, in which students cooperated in small groups whilst researching, designing and building structures for particular groups within Cambridge e.g. the allotment project as described in the Case studies part.[73]

What is less pronounced is the importance of an **interdisciplinary cooperation,** which can take place within the scope of the project, and which starts to appear in the programmes. The aim of this activity is to get used to the cooperation between an engineer and an architect. Engineering students bring "objective"(technical) aspects of structure into view, whilst architectural students promote their "subjective" (design) views, and together they need to find a suitable balance for their design. It is practiced e.g. at the **University of Cambridge**, where the third year architectural students work in mixed teams of 4 to 6 people with the fourth year engineering students. Their final project must contain appropriate calculations for light, sound, energy, heat and structure. Similar arrangement takes place at the **University of Bath** in the sixth term in the form of team design incorporating both architectural and engineering students.

Another example comes from **HCU Hamburg**, where the interdisciplinary project labelled as **A+ programme** runs in the fifth term jointly with the students from programmes like Urban Planning, Civil Engineering, Geomatics, and Metropolitan Culture. **RWTH Aachen** organizes the **interdisciplinary project**, **specialised on the structure** in the fourth term. Within the scope of the project, structural concepts should be presented by alternatives, and supporting structures must be optimally designed, taking into account comprehensive structural engineering aspects. Transdisciplinnary **project UdK Campus-Collisions** started in winter term 2013/14, and supports and promotes an artisctic-scientific atitude to learning.

[73] see p.280

Activities such as **field trips** or **professional practice** are also benfitiary, because the students get in touch with the real working environment. There is a field trip in the first term and regular site visits in the second term of the year 1 at the **University of Cambridge** and Studio work is overseen by practicing architects. There is also a compulsory 5-7 days Study Trip abroad to a European city, which takes place around Easter and focuses on visiting famous buildings in the chosen city. The second year field trip takes part during Christmas holiday, lasts 3-4 days and is voluntary. Students also take **regular visits to two buildings currently under development** during the year 3 subject Advanced Studies in Construction Technology, and also attend lectures given by the members of design teams, who work on these buildings. At the end of the term, students must submit a case study notebook, which counts towards their grade. **Professional practice** is included in the curriculum of the **University of Bath** as well, where **6 months** are reserved for it in the fourth year. The **University of Edinburgh** runs a **field trip to a European city** in year 2 (and actually situate students' design projects in there), organizes **guest lectures** as a part of Technologies block, and in the year 3 there are **30 ECTS credits** (half of the yearly amount) devoted to a **professional practice**, which runs simultaneously with other subjects **during the whole year**. **UCL London** organizes compulsory **field trip** to European city in the second semester of year 1.

Excursions organised by the Department of Structural Design from **ETH Zurich** are topical. Previous destinations included for example the first famous henebique structures - the Moulins de la Loire or La Cité Radieuse de Le Corbusier, **natural form of concrete in Rome**, students explored the integration of **geometrical and structural principles in the work of Gaudi** and his followers in Barcelona, or observed and documented the **interplay between architecture and construction on examples from industrialist cities Manchester and Liverpool.**

The professional practice is compulsory also at German universities, e.g. there is **12 weeks** of compulsory construction site internship at **HCU Hamburg**, a requirement students have to meet before the end of the year 1, and is recommended to fulfill before actually starting university. **ABK Stuttgart requires 3 months of manual internship** before students start their studies and **further 2 months of office work** praxis before submitting bachelor thesis. The comittments can be spread.[74] **Compulsory** professional practice is also at the **UdK Berlin**.

All of the universities from the sample run **various workshops**, which further deepen structural knowlede and which are very popular with students. To name several interesting activities, there has been a **masonry workshop at MIT** running for approx half a year in

[74] see p.306

2009/2010, starting in Spain and continuing at MIT[75]. There was a bamboo workshop at RWTH Aachen, or **topical workshops at TUM** (2015 Transformation, 2016 Curvature-bending the rules, 2017 gridshells, 2019 experimental structures).

Quite often are also **"summer schools"**, when students combine trip to follow particular topic with an actual fabrication on the site (e.g. shelters at Champagne by TUM or Manchester's Norwegian summer school related to Wittgenstein). Summer schools are run also by the UCL London, or by the University of Cambridge.

Several **competitions** are also opened by universities to boost students' interest in subject, e.g. there is a **third year prior prize for the best understanding of structure** at the University of Cambridge, "**The Breaking Trial**"[76] run by the Chair of Structural Design of RWTH Aachen or **"Bridge" and "Tower"**[77] making competition at the Taubman's college of Architecture at the University of Michigan, USA.

[75] https://vaulting.wordpress.com/page/3/, visited Jan 2019; also see p.242

[76] http://arch.rwth-aachen.de/cms/Architektur/Die-Fakultaet/Aktuell/Nachrichten/~clvd/MyReiff-HTML-Einzelansicht/?file=2008-01-09, visited July 2019; also see p.319

[77] http://www.structures1.tcaup.umich.edu/bridges2/bridges2.php, visited July 2019; see also pp.350-351

Case studies conclusion

Prof. Chiuini from the Ball University, Muncie, Indiana, USA, has (in his paper on teaching structures[78] at architectural schools) brought to attention the **quote of Richard Bender**, stating that: "The **classical sequence of presenting statics, strength of materials, analysis and 'design'** may represent a logical progression of information. However, divorced as it usually is from involvement with the total process of design, this sequence has resulted in architectural graduates who have no understanding of the basic principles involved, cannot apply them, nor retain for a significant period after graduation the basic core of material encountered." The quote appeared originally in Black and Duff's 1994 article[79] describing six-year long experiment concerning an unconventional teaching approach (incorporating specialised software) at the University of California, Berkeley, USA.

After thoroughly analyzing the study plans of eleven selected European English and German speaking universities (**ABK Stuttgart, HCU Hamburg, RWTH Aachen, TU Munich, UDK Berlin**, **UCL London, University of Bath, University of Cambridge, University of Edinburgh, University of Manchester**, **ETH Zurich, Switzerland),** and having look at the teaching approach of **MIT Boston, Cambridge, USA**, as well as going through approximately fifty conference papers discussing various activities applied to structural teaching at architectural schools, I came to a conclusion, that although quite a substantial amount of time has passed, the setting of architectural structural curricula is moreless the same "classical sequence...representing a logical progression of information...", a fact which to a certain point proves the importance of logical arrangement of the knowledge that needs to be passed to students.

What has however greatly improved since is a noticeable shift in the original lack of involvement in the process of design, which was achieved by more close relation between the statics courses and project, by the implementing enhancing activities supporting better understanding (experiments, site visits, workshops), by using specialised software (taking over complicated calculations, virtual modeling), and mostly by applying modern teaching methods (hands-on-learning, problem learning).

[78] CHIUINI (2006)

[79] BLACK, DUFF (1984)

C ANALYTICAL-SYNTHETIC PART

C1 QUANTITATIVE ANALYSIS

Studies on share of SE subjects in curricula at selected European faculties of architecture.

Longterm objective of the quantitative research has been set up as an analysis of the importance of Structural Engineering within the architectural curricula of selected universities. For this purpose **methods of applied research** has been used: analysis of the study plans as well as comparison of the percentual share of Structural Engineering subjects in architectural curricula (using volume of ECTS credits[80] devoted to Structural Engineering).

[80] All the selected universities use European Credits Transfer and Accumulation System (ECTS), which represents a standard for comparing the study attainment and performance of students of higher education across the European Union and other collaborating European countries. For successfully completed studies ECTS credits are awarded. One academic year corresponds to 60 ECTS credits that are equivalent to 1500-1800 hours of study in all countries. This standard proved useful as an objective quantity indicator.

Introductory study

“Share of Structural Engineering in Curricula at Selected European Universities” [81]

Specific objectives:

- to get an initial insight into problematic
- to get % volume of SE subjects in curricula
- to compare volume of SE in Architectural/Civil Engineering courses
- to form hypotheses

Selection criteria: for the initial comparison with CTU in Prague, 2 leading English speaking universities (UB – University of Bath, United Kingdom, ICL- London Imperial College, United Kingdom) and 2 leading German speaking universities (TUM– Technical University of Munich, Germany, ETH – ETH Technical University of Zurich, Switzerland) were selected

- university ranking charts[82]
- following master and bachelor study programmes were compared:
  Architectural Design
  Architectural Engineering
  Civil Engineering (Building Structures specialisation only)
- courses taken into account:
  Structural Mechanics, Statics, Concrete Structures, Steel Structures, Wooden Structures and Foundations

Results: Structural Engineering as a proportion of curricula

- Structural Engineering represents around 20-40% of Civil Engineering curricula.
- In Architecture Courses, it represents less than 15% of bachelors and 0-5% of masters curricula.
- 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).

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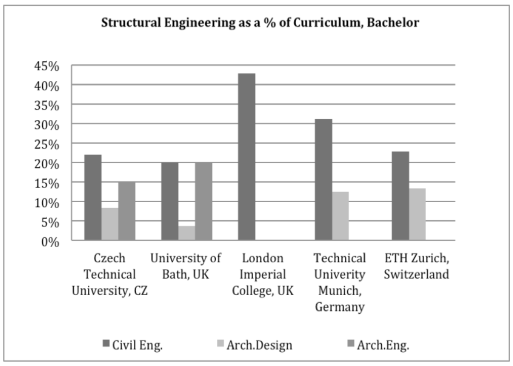
[81] POSPISIL, VAVRUSKOVA (2013)

[82] university rankings p.29

- 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).
- The Czech Technical University in Prague has the lowest share of Structural Engineering in its Civil Engineering courses (22% bachelor-26%master). In Architectural Design Courses, 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.

Additional notes:

- As already mentioned (in paragraph 3), only two out of the selected universities (Czech Technical University in Prague, Technical University Munich) offer the combined courses of Civil Engineering and Architectural Design (Architectural Engineering), which is the reason of the data absence in graphs for the rest of the universities (third column).
- London Imperial College offers no Architectural Design courses at all. This fact is the reason for data absence.
- No data shown in all other cases represents the fact, that share of Structural Engineering is 0%.



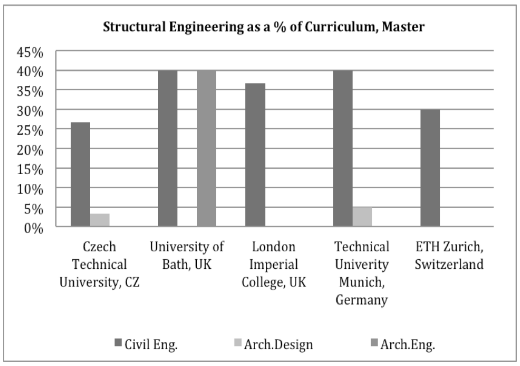


Fig. C1.1 SE as a % of bachelor curricula (left)

Fig. C1.2 SE as a % of master curricula (right)

Results: Structural Mechanics and Structural Design mix within the curricula

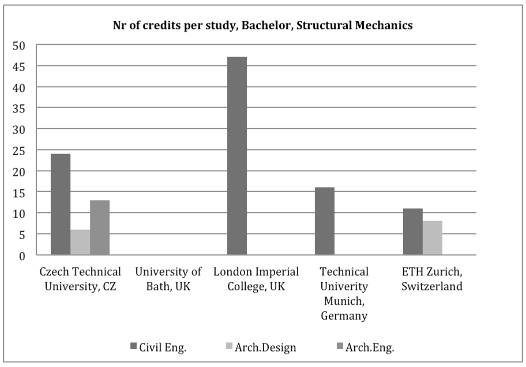
Structural Mechanics is a preparatory theoretical course that gets students accustomed with the basic laws and principles of mechanics. In follow up courses students further concentrate on applying these principles to design various structures.

Following observations for **bachelor courses** have been made:

- As far as **Civil Engineering** courses are concerned, all the selected universities include in their curricula preparational stage of Structural Mechanics, that is on average between 11 and 24 credits per study. Seeming absence of this course at University of Bath is due to the fact, that this stage is not being taught on its own, but as an introduction to Structural Design.
- The largest emphasis on theoretical **Structural Mechanics** in **Civil Engineering courses** is put by London Imperial College, which has got two to four times more credits per study (47 credits) than other universities. It is also the only university, which puts more emphasis on preparational stage, the follow up related subjects have one third less credits – only 30 per study, which is still the average amount of Structural Design courses overall.
- The volume of follow up courses of **Structural Design** in **Civil Engineering** varies slightly between 30 to 40 credits per study.
- The share of Structural Mechanics vs. Structural Design for **Architectural Engineering** curricula can only be compared for two universities which offer this type of programme (Czech Technical university in Prague, University of Bath). Eventhough they are distributed differently (CVUT-Structural Mechanics 13 credits, Structural Design 23 credits vs. UB –Structural Mechanics 0 credits, Structural Design 36 credits), their overall volume is identical and consists of 36 credits per study.
- **Architectural Engineering** programmes have significantly higher volume of Structural Engineering subjects (36 credits) in comparison to Architectural Design (9-15 credits).
- Half of the universities which offer **Architectural Design** courses do not have preparational stage of Structural Mechanics on its own, it is incorporated into Structural Design.
- The biggest emphasis on Structural Design as a part of the **Architectural Design** course is put on by Technical University of Munich, which has around 30 credits of Structural Egineering. It represents twice the average amount.

Following observations for **master courses** have been made:

- As far as the proportion of Structural Mechanics vs. Structural Design is concerned, in master courses, the graphs reflect the fact, that there are no preparatory courses at this stage of study, which was expected.
- The part of the graph reflecting the situation in **Civil Engineering** furthemore shows that German speaking universities Technical university of Zurich and Technical University of Munich have double the amount of Structural Design courses than other universities.
- In master studies of **Architectural Design** is Structural Design taught only at two universities (Czech Technical University,Technical University of Munich), but its volume is visibly reduced in comparison to bachelor part of the studies to maximum of 5 credits per the whole master study (usually 120 credits).
- Totally opposite approach to Structural Design subjects at master studies for **Architectural Engineering** is applied by the two participating universities. At Czech Technical University, no Structural Design subject is being taught at this stage at all with the comparison to University of Bath, where the amount of Structural Design stays on the same level as for the Civil Engineering students.



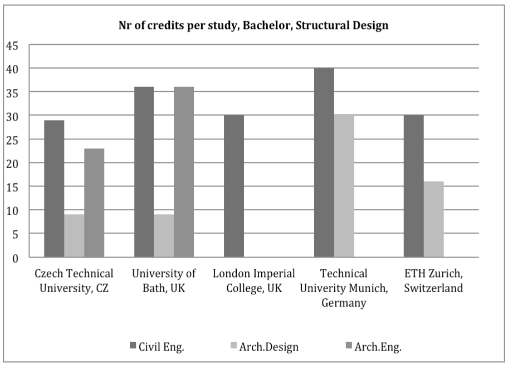
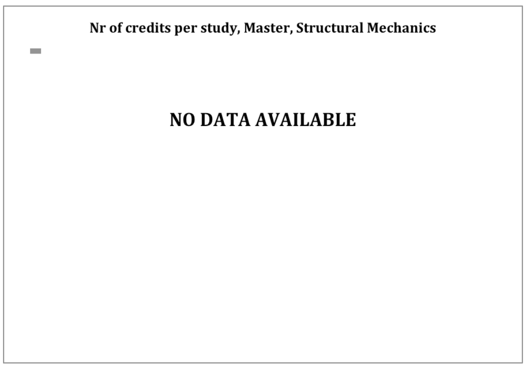


Fig. C1.3 Nr. of credits per bachelor study for Structural Mechanics (left)

Fig. C1.4 Nr. of credits per bachelor study for Structural Design (right)



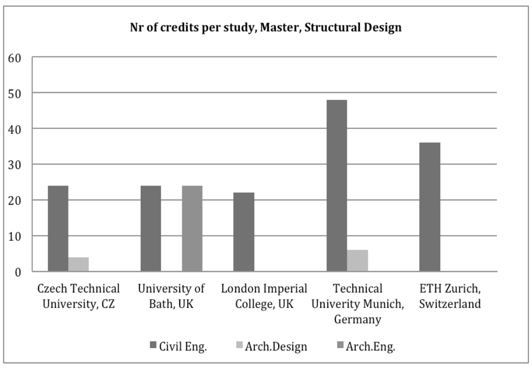
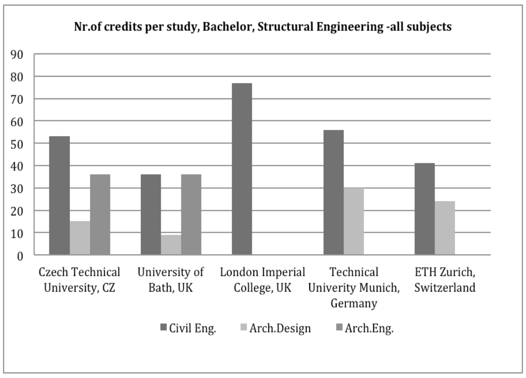


Fig. C1.5 Nr. of credits per master study for Structural Mechanics (left)

Fig. C1.6 Nr. of credits per master study for Structural Design (right)



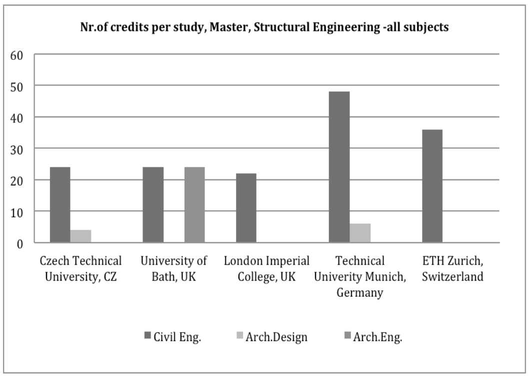


Fig. C1.7 Nr. of credits per bachelor study for SE - all subjects (left)

Fig. C1.8 Nr. of credits per master study for SE - all subjects (right)

Conclusions and hypothesis forming

- **Lower volume of SE subjects in architectural courses** (less than 15% of bachelors and 0-5% of masters curricula) **compared to civil engineering courses** (around 20-40% in the whole study) **is well known fact** – it was only looked at it in the research in order to get some “real data” on the ratio.
- The research provided interesting results on volume of SE subjects in curricula of **“combined” courses on Architectural Engineering** – the two universities that are offering such courses show completely opposite attitude: **whilst CTU has no SE subjects in its master curricula, at University of Bath the volume of SE subject in curricula increases towards the end of the studies, where it is comparable to the volume of civil engineering courses.**
- R**elatively high percentage of Structural Engineering subjects in bachelor Architectural Design curricula at German speaking universities** have been noticed **(around 15 %) compared to other European universities (cca 5-7%)**, which led to the forming of the following hypotheses:

Hypothesis H1

The percentual share of SE subjects in bachelor architectural curricula of German universities is higher compared to other European universities.

Hypothesis H2

The share of Structural Engineering subjects at Faculty of Architecture at CTU in Prague is underrepresented in context to other selected European English and German universities.

Follow - up study

"Share of Structural Engineering in Curricula of CTU vs. Selected European Faculties of Architecture" [83]

Specific objectives:

- to get % volume of SE subjects in curricula on broader sample (27 selected German (15) and English (12) speaking universities
- to compare % volume of SE subject for CTU vs. other selected European universities
- to validate/refute hypothesis: ? Are German universities putting bigger emphasis on their architectural students' understanding of Structural Engineering by devoting more lessons to it in their curricula compared to other European universities?
- to formulate new hypotheses

Selection of European English and German "speaking" universities

- selection is based on rankings listed in bibliography[84]
- another criteria taken into account whilst conducting the selection was further possibility of broadening initial quantitative analysis into extended qualitative survey, which is planned in the form of sociological research with exchange students from CTU

Fig. C1.9 Map of selected universities

[83] POSPISIL, VAVRUSKOVA (2014)
[84] universities rankings: see p.29 and p.170

List of the selected universities as shown on the map:

English speaking universities – England, United Kingdom

1. UB University of Bath, England
2. UC University of Cambridge, England
3. WSA Welsh School of Architecture, University of Cardiff, England
4. UL University of Liverpool, England
5. UCL University College of London, England
6. NCL Newcastle University, England
7. NTU University of Nottingham, England
8. SSoA School of Architecture, University of Sheffield, England

English speaking universities – Ireland, United Kingdom

9. UCC University College Cork, Ireland
10. UCD University College Dublin, Ireland

English speaking universities – Scotland, United Kingdom

11. UE University of Edinburgh, Scotland
12. UG University of Glasgow, Scotland

German speaking universities – Germany

13. RWTH RWTH Aachen
14. TUB Technical University of Berlin
15. AHS Alanus University, Bonn
16. TUD Technical University of Dresden
17. FH FFM Frankfurt University of Applied Sciences
18. HCU Hafen City University, Hamburg
19. LUH Leibniz University of Hannover
20. TUM Technical University of Munich
21. ABK ABK Stuttgart
22. TUS Technical University of Stuttgart
23. BUW Bauhaus University Weimar

German speaking universities – Austria

24. TUG Technical University of Graz
25. KUL University of Art and Design Linz
26. TUW Technical University of Wien

German speaking universities – Switzerland

27. ETH Technical University of Zurich, Switzerland

University conducting the study – the Czech Republic

Results: Structural Engineering as a Proportion of Curricula

Following observations for **bachelor courses** have been made:

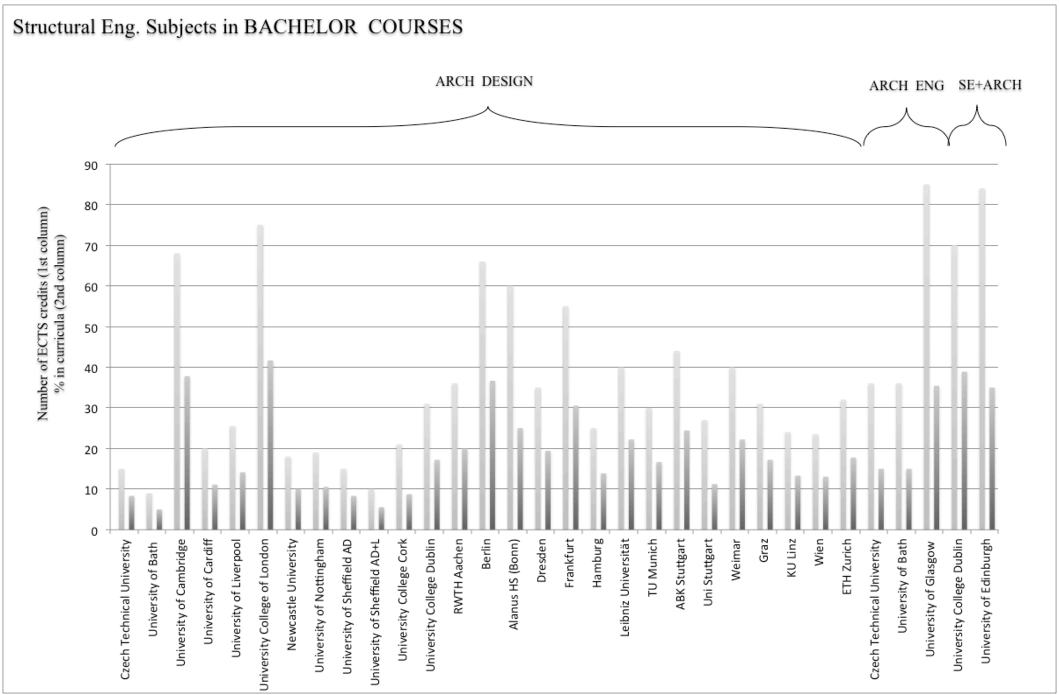


Fig. C1.10 Structural Engineering subjects in bachelor studies at selected European universities

- **Length of bachelor architectural courses**. Bachelor architectural courses at most universities from the sample take three years. The exceptions, where such courses take four years, include for example Technical University of Stuttgart and Alanus University of Bonn. The Scottish universities, University of Edinburgh and University of Glasgow, also have four-year bachelor studies, but they have one year shorter architectural masters studies. University of Bath has a three-year Architectural Engineering course followed by one-year professional placement.
- **Share of Structural Engineering in bachelor architectural curricula**. Overall share of Structural Engineering in bachelor architectural curricula ranges between 5-42% within the sample.
- **Architectural Design vs. Architectural Engineering courses**. Most architectural courses are offered as Architectural Design. Architectural Engineering courses are offered only at three universities from the sample, The Czech Technical University, University of Bath and University of Glasgow. Interestingly, share of Structural Engineering in bachelor curricula does not differ significantly between Architectural Engineering and Architectural Design courses, typically ranging between 15-35%.
- **Combined courses of Structural Engineering and Architecture**. Two universities from the sample, University of Edinburgh and University College of Dublin, also offer

combined courses of Structural Engineering and Architecture. Share of Structural Engineering in curricula of such bachelor courses ranges between 35-39%.

- **German vs. English speaking universities**. In general, Structural Engineering represents higher share of architectural bachelor curricula at German-speaking European universities (Germany, Austria, Switzerland) vs. English-speaking European universities. Such share ranges between 15-25% for the former compared with 10-15% for the latter.
- **Share of Structural Engineering in bachelor architectural curricula vs. ratings of universities**. While, as explained above, the overall share of Structural Engineering in curricula of bachelor architectural courses is generally higher in German-speaking European universities vs. English-speaking European universities, two British universities represent an exception. Architectural bachelor curricula at University of Cambridge and University College in London have 38% and 42% share of Structural Engineering, which is among the highest from the sample. It was also noted that these two universities belong to the top rated British and European universities.
- **Share of Structural Engineering in bachelor architectural curricula at The Czech Technical University**. Structural Engineering represents only 8% of the bachelor architectural curricula at the Czech Technical University, which is among the lowest within the context of the European sample, where such share typically ranges between 10-25%. This share is for example approximately 80% lower compared to the leading UK universities and 45-67% lower compared to German-speaking universities from the sample.

Following observations for **master** courses have been made:

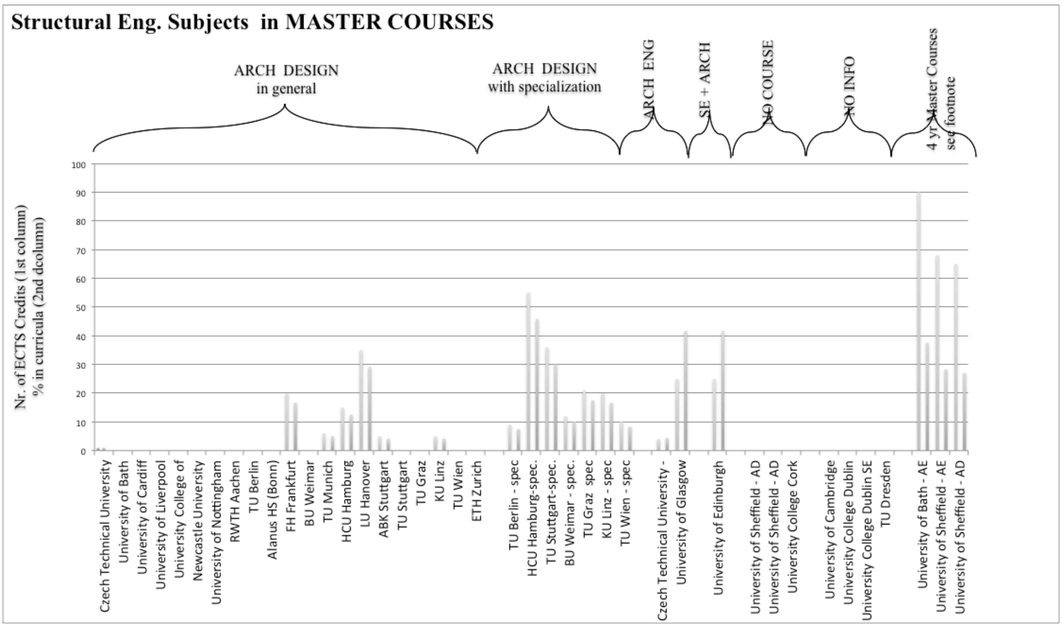


Fig. C1.11 Structural Engineering subjects in master studies at selected European universities

- **Length of master architectural courses**. Master architectural courses at most universities from the sample take two years, following three-year (exceptionally four-year) bachelor courses. As mentioned about the two Scottish universities, University of Edinburgh and University of Glasgow, offer four-year bachelor courses followed by one-year master courses. University College of Cork, Ireland, offers bachelor, but no master courses in architecture.
- **Share of Structural Engineering in master architectural curricula**. The share of Structural Engineering on Architectural Design curricula is significantly lower compared to that for bachelor curricula in the sample of universities, usually below 5%. Three German universities, FH Frankfurt, LU Hanover and HCU Hamburg, represent an exception with such share in a range of 12-29%.
- **Architectural Design vs. Architectural Engineering courses**. As mentioned above, Architectural Engineering courses are offered only at three universities from the sample, The Czech Technical University, University of Bath and University of Glasgow. Share of Structural Engineering in Architectural Engineering master curricula ranges between 4-42%.
- **Architectural master courses with specialisation on Structural Engineering**. Some universities offer further specialisation on Structural Engineering as part of their architectural master courses. These include for example TU Berlin, HCU Hamburg, TU Stuttgart, BU Weimar, KU Linz and TU Vienna. This specialisation boosts the share of Structural Engineering on architectural master curricula to 10-45%.
- **Combined courses of Structural Engineering and Architecture**. As mentioned above, two universities from the sample, University of Edinburgh and University of Glasgow, also offer combined courses of Structural Engineering and Architecture. Share of Structural Engineering on curricula of such master courses is around 42%.
- **Masters-only architectural courses**. Some architectural courses are available as master only and they take four years. These include Architectural Engineering at the University of Bath and Architecture Courses at Sheffield University. Share of Structural Engineering on curricula of such courses ranges between 27-37%.
- **Share of Structural Engineering in architectural master curricula at The Czech Technical University**. Architectural Design master courses at The Czech Technical University have no Structural Engineering in their curricula, similarly to approximately two thirds of universities from the sample. Curricula of the Architectural Engineering master courses provided by the Faculty of Civil Engineering at The Czech Technical University contain approximately 4-5% of Structural Engineering. This share is considerably lower compared to European alternatives such as combined courses of

Structural Engineering and Architecture or Architectural Design with specialisation on Structural Engineering.

Additional notes:
There were no specific data on curricula available for master architectural courses at the following universities from the selection: University of Cambridge, University College of Dublin, TU Dresden.

Conclusions, evaluating previous hypotheses, forming new hypotheses

- Structural Engineering **appears to be an important** part of architectural curricula at all European universities, especially for the bachelor courses.
- That said **share of Structural Engineering on architectural curricula varies considerably** among the analysed universities, **ranging between 5-42% in bachelor courses and 0-45% in master courses**. This among others depends on whether the courses are offered as 'pure' Architectural Design on one hand or Architectural Engineering (possibly Architectural Design with specialisation on Structural Engineering) on the other.
- **German speaking and the top rated UK universities tend to have higher than average share of Structural Engineering** in their architectural curricula. **In bachelor studies,** Structural Engineering represents **around 35% of curricula at leading British universities and at architectural engineering combined courses. Most English-speaking European universities have 10-15%** of Structural Engineering in their curricula. **German speaking European universities** (Germany, Austria, Switzerland) **show overall higher volume of Structural Engineering** in their courses, **which varies between 15-25%. For majority master** architectural courses, Structural Engineering subjects represent **up to 5%** of curricula. Some universities offer **further specialisation** in Structural Engineering, which **boosts** share of Structural Engineering subjects in their curricula **to 10-45%**
- Finally, **with 8.33% share in bachelor studies, Structural Engineering subjects at the Faculty of Architecture, Czech Technical University in Prague, seem to be underrepresented in context** of the above-mentioned European universities, where such share most typically ranges between 10-25%. I can therefore regard the hypothesis H2 as valid. Share of Structural Engineering on architectural curricula at The Czech Technical University is also low in curricula of the Architectural Engineering bachelors and master courses provided by the Faculty of Civil Engineering in comparison with similar

European Architectural Engineering or Architectural Design courses with specialisation on Structural Engineering.

- I would like to further investigate the assumption expressed by a new hypothesis **H3**:

Hypothesis **H3**:
Volume of Structural Engineering subjects in architectural curricula is on comparable levels for selected major Czech (and potentially Slovak – because of joint history as Czechoslovakia in the years 1918-1992) technical universities.

- In accordance with the above results of the survey, I think that the **hypothesis H1 has been partly verified: German universities from the sample show higher percentual volume of Structural Engineering courses in their bachelor architectural curricula** compared to CTU and majority of English speaking European universities.
  However, share of SE subjects at the top rated British universities (University of Cambridge, University College of London) is even slightly higher then that of German universities and comparable to the amount of SE at Architectural Engineering/ Architecture with Structural Design specialisation.
- **Bigger percentual volume of SE subjects in bachelor architectural curricula is typical for top rated universities, which might suggest direct link** between the two facts.

In order to further investigate reason behind **H1** (are they covering more areas of SE? / are they covering comparable extent of SE but in wider context? / are they covering comparable range of topics, but assigning more time to practice?), a new hypothesis **H4** has been formulated as follows:

The new hypothesis H4:
Having allocated more time to Structural Engineering in their bachelor architectural curricula, students at German and the top rated British universities are taught wider range of SE topics than students at other European faculties of architecture compared in the selection.

Supplementary study

„Structural Engineering in Architectural Studies“[85]

(New ways of teaching Structural Engineering
and its share in curricula at selected Czech and Slovak Technical Universities)

Specific objectives:

- to compare % volume of SE subjects in curricula of selected Czech and Slovak technical universities
- context of teaching methods

Selection criteria:

- following universities were chosen for the analysis in accordance with ranking charts[86]

Brno University of Technology, Czech Republic (BUT)
Czech Technical University in Prague, Czech Republic (CTU)
Slovak University of Technology, Bratislava, Slovakia (STU)
Technical University of Ostrava, Czech Republic (TUO)
Technical University of Liberec, Czech Republic (TUL)

Results and evaluating hypotheses:

Structural Engineering as a Proportion of Curricula at Selected Czech and Slovak Universities

Following observations for **bachelor courses** have been made:

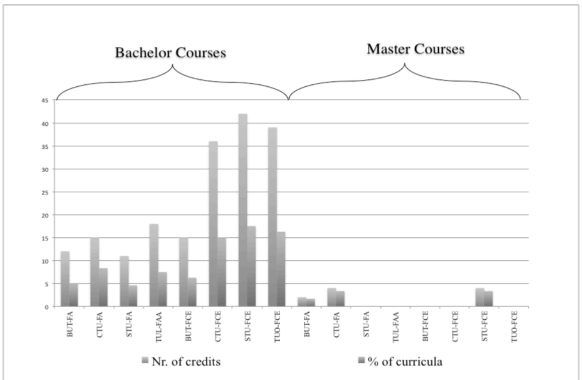


Fig. C1.12 Structural Engineering in curricula at selected Czech and Slovak technical universities

FA Faculty of Architecture
FCE Faculty of Civil Engineering
FAA Faculty of Art and Architecture

[85] POSPISIL, VAVRUSKOVA (2015/1)
[86] university rankings; see p.29 and p.170

- At faculties of architecture in the sample share of Structural Engineering subjects ranges between 5-8% of curricula (11-18 credits per the whole study). Faculty of Architecture at CTU and Faculty of Art and Architecture at TUL have higher share of Structural Engineering in their curricula compared to the other two faculties from the sample; 8.33% (11 credits) and 7.5% (18 credits) respectively vs. approximately 5%. (see additional note 1 at the end of a chapter)
- At faculties of civil engineering, share of Structural Engineering subjects is typically around 15% of curricula with approximately 40 credits per the whole course. With its 6.25% of curricula and 15 credits Structural Engineering subjects appear underrepresented at BUT.

Following observations for **master courses** have been made:

- Share of Structural Engineering subjects is represented less in the master courses vs. the bachelor courses.
- Structural Engineering accounts for less than 5% in 3 of 8 faculties from the sample. It is not represented in master courses in the remaining ones.

Additional notes:

- Lower percentual share of Structural Engineering subjects in curricula of faculties of architecture at TUL vs. CTU (despite higher volume of credits) is due to the shorter length of study at CTU.
- Both in its master and bachelor courses, most of the universities from the sample offer further optional courses which can boost the share of Structural Engineering subject by 2-6 credits in total.

Share of Structural engineering Subjects in Curricula of Selected Czech and Slovak vs. Selected European Universities

- Structural Engineering represents between 5-8% of bachelor curricula at faculties of architecture and around 15% of similar curricula at faculties of civil engineering in the Czech Republic and Slovakia. Most European English speaking universities have 10-15% of Structural Engineering in their curricula, however at leading British universities (UCL London, Cambridge) and for combined courses (Architectural Engineering) its share represents around 35% of curricula. In comparison to English speaking European universities, German speaking European universities show overall higher volume of

Structural Engineering in their courses, which varies between 15-25% [87]. Share of Structural engineering in curricula for master courses from the sample of selected Czech and Slovak technical universities is comparable to one of selected German and English speaking universities with values in the range between 0-5%. Some foreign universities however offer further specialisation in Structural Engineering, which boosts its share in curricula to 10-45%.

Conclusions and evaluating hypotheses

- **Share of Structural Engineering subjects ranges between 5-8% in bachelor architectural curricula and up to 5% in master architectural curricula at selected Czech and Slovak technical universities.** The results support hypothesis H3, which expected them to be on similar level.
- Share of Structural Engineering in bachelor architectural curricula at selected Czech and Slovak technical universities seems to be underrepresented in the context to selected European universities, where the share typically ranges between 10-15% at most English speaking universities and between 15-25 % at most German speaking universities.
- Share of Structural Engineering in master curricula at Czech and Slovak universities (up to 5%) is comparable to this of European universities. Some foreign universities however offer further specialisation in Structural Engineering, which boost its share in curricula to 10-45%.
- I cannot evaluate potential consequences of the above results fact at this stage of the research, but I plan to further analyze content of the Structural Engineering at architectural courses (qualitative analysis) to draw further and more detailed conclusions on this subject.

[87] POSPISIL, VAVRUSKOVA (2014)

Additional supplementary study

“Teaching Structural Engineering to Architects"
(Structural Mechanics vs. Structural Design mix within the curricula)[88]

Specific objective:

- to examine approach of particular universities from the sample as far as Structural Mechanics vs. Structural Design mix within their architectural curricula is concerned

Observations, results

Types and duration of architectural courses

- Bachelor courses of Architectural Design (AD) at universities from the sample take three years all with the exception of University of Bath, UK and TU Munich, Germany (both have compulsory additional year designated for architectural practice resp. for studying abroad). Two other universities from the sample (Uni Stuttgart and HS Alanus Bonn, Germany) have recently changed its curricula schedule from 4-year programme to 3-year plan.
- Bachelor courses can be later followed by master courses in the duration of additional two years.
- When the research took part in 2014, only five out of the 27 selected European universities (University of Edinburgh, University of Dublin, University of Glasgow, University of Bath, CTU in Prague) offered Architectural Engineering (AE) courses; at the present time they are offered also by UCL London, University of Cardiff, Sheffield and Liverpool, UK. Their length varies between 3 to 4 years, they are categorised as either bachelor or master (see Fig.C1.15 and Fig.C1.16) and have its own study plans different from AD . To compare it with the situation in Germany, there are no specific AE courses, however students can choose Structural Engineering specialisation in their master studies of AE which results in even greater volume of their curricula devoted to SE in their later studies (up to 45% compared to 35-40% for specialised AE courses in the UK).
- As observed earlier, Structural Engineering seems to have an important position in bachelor stage of both AE and AD studies (Pospisil, Vavruskova, 09/2014), therefore I would like to focus on bachelor architectural studies in this paper. Position of SE subjects in master studies further polarizes into practically disappearing from the

[88] POSPISIL, VAVRUSKOVA (2017)

curricula of AD and/or playing dominant part for the AE curricula.

<u>Structural Mechanics (SM) vs. Structural Design (SD) mix within the curricula</u>

- Structural Mechanics (SM) courses represent theoretical introduction into basic laws and principles of mechanics, on which further builds up Structural Design (SD) with detailed design of particular structural members. In order to illustrate general situation concerning SE subjects in architectural curricula, I would like to present Fig.C1.13 (bachelor AD) and Fig.C1.15 (bachelor/master AE), which show both volume of SE subjects (number of ECTS credits) and its % share curricula. German speaking and top-rated English speaking universities from the selection show overall higher volume of SE subjects in their bachelor AD curricula.

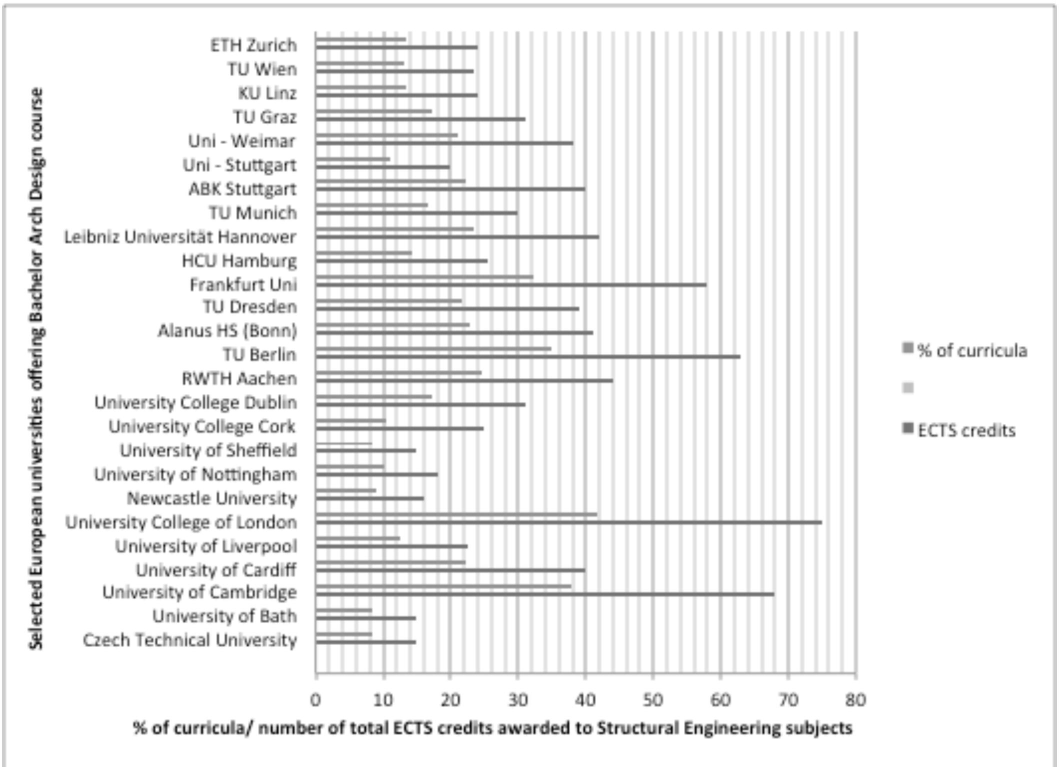


Fig.C1.13 SE subjects in bachelor AD curricula

- As seen on Fig.C1.14, the ratio of SM vs. SD subjects in the bachelor AD curricula ranges considerably within selected universities.

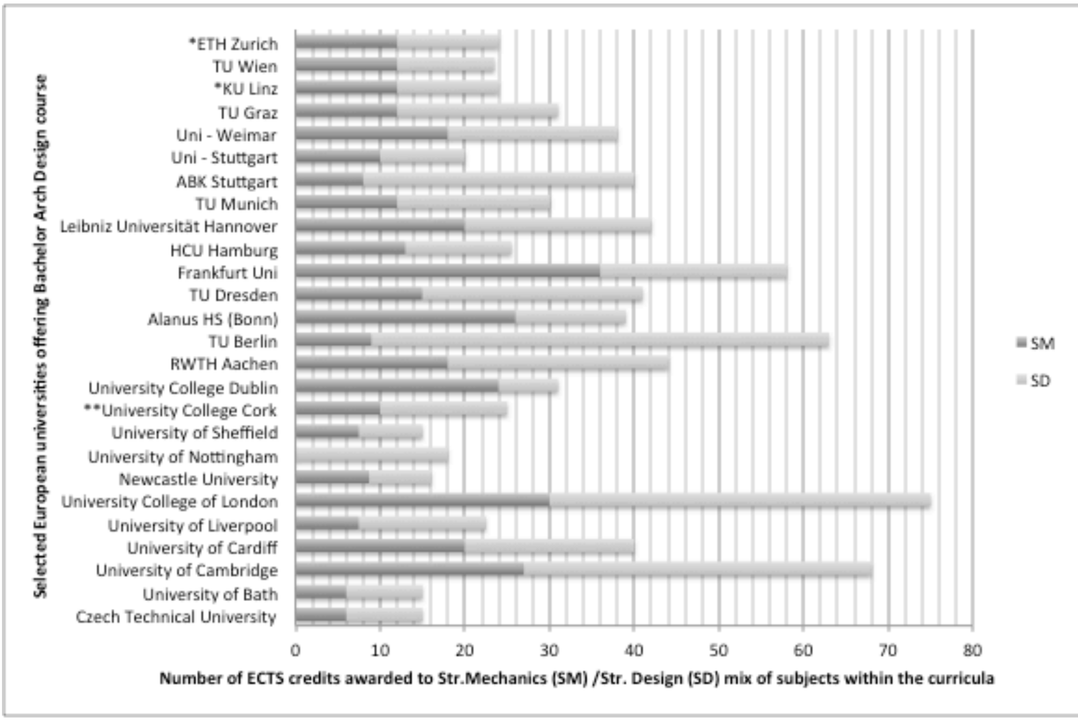


Fig.C1.14 Mix of SM vs. SD subjects in bachelor AD curricula

- Following figures (Fig.C1.15, Fig.C1.16) illustrate analogically the situation concerning AE curricula. On the contrary to SM/SD mix within AD curricula, where general attitude towards its ratio cannot be conclusively identified, the amount of SM vs. SD seems to be equally ballanced in AE curricula.

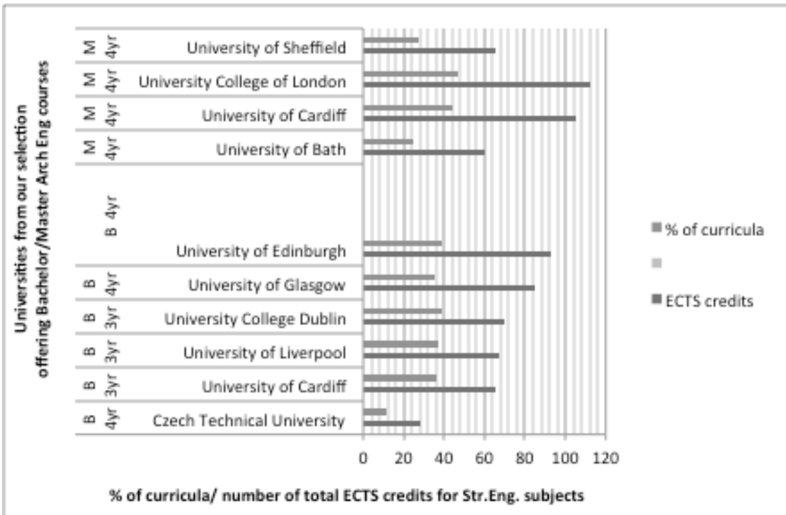


Fig. C1.15 SE subjects in bachelor/master AE curricula

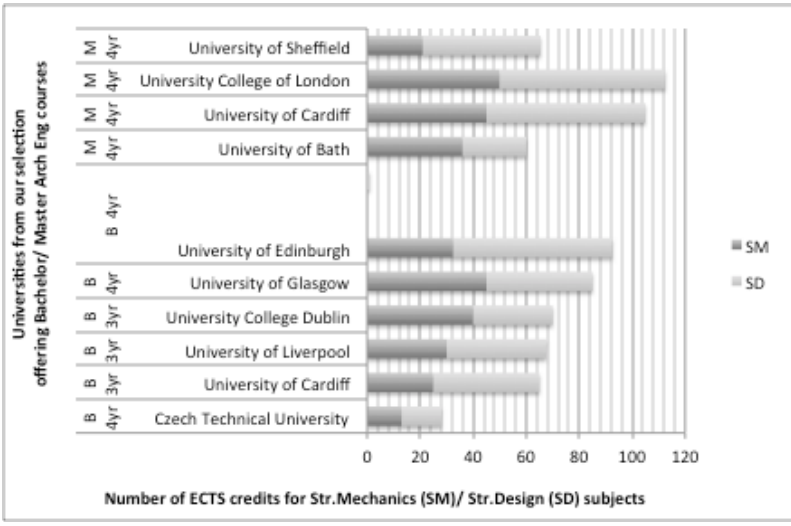


Fig.C1.16 Mix of SM vs. SD subjects in bachelor/master AE curricula

Conclusions, practical use of the research

- According to the findings, and especially for Architectural Design courses, the research has not found "universal" approach towards the problematics of optimal ratio of Structural Mechanics vs. Structural Design courses in curricula. Eventhough some universities from the selection put an emphasis on students' understanding of mechanics' principles (and put more theoretical SM lectures into their curricula), there seem to be a certain inclination towards predominant gaining practical skills (more SD), either by working on case Experimental Constructing in HCU Hamburg studies followed by individual projects or by "learning by doing" approach (e.g. or Practical structural modelling exercises at University of Nottingham, UK), that help students develop a basic understanding of structures' behaviour and understanding of the interaction between structural form and the loads the structures have to carry.
- Although it might seem that some universities show comparable amount of SE practice in their curricula, it would be worth conducting further detailed analysis, which would take into account the amount of SE practice within students' individual projects (e.g. both AD couurses at University of Bath and CTU in Prague show approximately same amount of SE subjects, however the first mentioned shows twice as much ECTS credits devoted to individual projects, which in my opinion reflects upon the time devoted to structural design.)

C ANALYTICAL-SYNTHETIC PART

C2 QUALITATIVE ANALYSIS

Studies on analyzing the methods and forms of teaching SE subjects at selected European faculties of architecture.

Longterm objectives has been set up as follows: to analyze the importance of Structural Engineering, to monitor innovative teaching methods, and to discuss suitable forms of lecturing Structural Engineering in architectural courses at selected European universities. **Methods of applied reasearch** have been used: comparison, observation and analysis.

Introductory study on teaching methods

„New Ways of Teaching Statics and Applied Structural Mechanics to Architects“ [89]

Specific objective:

- to get an initial insight into the problematics of different ways of teaching SE to architectural students

Results

- **introduction on the situation in higher education in the Czech Republic[90]**
- **overview of SE subjects within architectural curriculum at CTU in Prague**
- **introduction on various attitudes to lecturing SE at faculties of architecture**

SE courses in architectural curriculum at CTU in Prague:

- students **start with courses of theoretical mechanics** in summer term of their first year (Statics I) and continue in winter term of their second year of study (Statics II)
- **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
- Subsequent **course on Load-bearing Structures** follows in the next three terms of their study (completing the course coincides with the end of the bachelor course); the course introduces the elements of designing load-bearing structures – their space arrangement and dimensions according to material, such as masonry, reinforced concrete, steel and timber, all according to EuroCodes

Forming hypothesis and conclusions

New hypothesis **H5**:

Innovative teaching methods are more appropriate for teaching SE subjects to architectural students than traditional frontal methods.

[89] POSPISIL, VAVRUSKOVA, VERTATOVA (2014)

[90] see Problem statement p.18

Follow-up study on teaching methods

„Teaching Structural Engineering to Architects“

(Traditional vs. innovative methods of teaching (at CTU Prague and at selected European Universities))[91]

Specific objectives:

- to discuss different ways of teaching SE to architectural students
- to monitor innovative methods used for lecturing SE to future architects

Findings:

1. Didactic Theories

As recounted by Conway[92], lecturers should be aware of recent findings in the field of didactic theories of constructivist and behaviorist approach, which are going to help them find out the best teaching strategies. Whilst "Teacher-Centered Instructional and Behaviorist" approach had been preferred for most of the 20th century education, "Student-Centered Instructional and Constructivist" approach has recently took over and is praised by nowadays' educational psychologists.

1.1 Teacher-Centered Instructional and Behaviourist approach

When described by the behaviourist theory, learning can be viewed as a cycle of stimuluses from teacher, closely followed by a response actions from learners. It is the teacher's choice what he „transmits“, students are only passive recipients and their role is reduced to memorize and absorb delivered facts, then later "regurgitate" them during the exam. Active participation of students in the learning process is not encouraged. This method furthermore promotes individualism and competition and assumes that students learn all in the same way. Unfortunately, relatively high percentage of students taught in this way cannot solve the real life tasks they encounter (Orlich)[93].

[91] POSPISIL, VAVRUSKOVA (2015/2)

[92] CONWAY in PEDRON (2006), see fn.10

[93] ORLICH in PEDRON (2006)

1.2 Student-Centered Instructional and Constructivist approach

At the present time, the learning-centered model of education is considered as more appropriate, because it helps to develop nowadays highly sought skills such as critical thinking, ability to solve problems, work in a team and communicate.

The idea is best expressed using a quote by Confucius (Chinese philosopher, 450 BC): ***"Tell me and I will forget. Show me and I will remember. Involve me and I will understand."***

It promotes providing moderately challenging tasks by teachers under whose guidance students build on their experience. Problem solving further enhances development of critical thinking and skill to solve real-life problems. In the contrast to a traditional model, which uses problems after their content has been introduced, problem-based learning uses problem as a way to challenge students, motivate them and initiate learning. This approach also brings a great benefit in the form of strengthening students' ability to work as a team.
It can be implied, that education should be more deductively-oriented than inductively oriented, more process-oriented than product-oriented and more practice-oriented than technical skill-oriented.
For teacher is also very important to take into account the knowledge students "bring" from previous education/experience. The most effective, though time consuming, way to prepare them for further building up on so far gained knowledge (and check students' understanding of the problem as well) is discussing alternative conceptions.
Discussion is also recognised as an essential tool for fulfilling the requirements of social aspects of learning. Students are taught to articulate their own views, exchange ideas and reflect both upon views of others and (critically) upon their own views. It gives them the opportunity to explain and justify their views and getting experienced and more fluent in "language of science". They should react to feedback from others, reorganize their views when necessary, negotiate and seek consensus. Person involved in a discussion must listen to the views of others in order to make up its own mind whether to agree or not. Role of the teacher is to support the interaction and assist the students with formulating their views.

2. Teaching methods in Higher education

The study would like to compare two main attitudes to teaching Structural Engineering to architectural students as described by Pedron (2006).

2.1 Traditional teaching methods

Traditional approach has been formed as a reflection of development of scientific thinking. Important role of engineering for the design and construction of buildings led to introducing sophisticated mathematic models into the educational process. However adequate this is for students who are used to scientific subjects, it could be less appropriate for students who have difficulty to study in a rational way. This problem is especially apparent when teaching Structural Analysis to architecture students. Compared to civil engineering students, they are less interested in mathematics, they are used to learn in visual, creative way. Their motivation to learn Structural Analysis is furthermore reduced by the absence of related subjects in their later studies. It has been observed, that some students apply the methods as a routine without considering whether it makes sense. Students might be competent at applying a set of instructions, but they get into difficulties if they need to apply the knowledge in a different context. Students often do not understand the basic structural concepts or how structures work (e.g. they have difficulty distinguish between tension or compression in bars, why the diagonal in truss may need to change its direction, where the simple structure like a continuous beam is most stressed, how the length of cantilever beam influences bending moments and displacements etc.). In order to meet students' needs and increase their interest, it is advisable for teachers to adopt alternative ways of teaching Structural Analysis.

2.2 Innovative teaching methods

The innovative methods (successfully used for several years at other universities e.g. ETH Zurich) can be divided into three main categories:

2.2.1 Learning by doing (hands-on experiments)

These ***experiments on a really small structure*** are considered by some tutors as especially suitable for students of architecture, who are used to learn in a visual way. It helps them better understand fundamental principles of a structural behaviour. Lecturers under the guidance of professor Künzle at ETH Zurich, Switzerland created series of demonstrations for the first course of structural analysis for their architectural students.
As described in professor Künzle's textbook[94], some of the class demonstrations are:
1. Simple beam structures where a wooden beam is supported at both ends with one horizontally moveable support and loaded in the middle. Students observe bending of the

[94] KUENZLE (2005)

beam when the moveable support moves. By further increasing the loads they can observe the linear proportionality between displacements and loads. Differences in elastic behavior of various materials can be seen when using beams of different material whilst keeping the same structure including its support and loading conditions

2. Most typical experiment for simple frames shows the comparison in behavior of a two-hinged, three-hinged and a fixed wooden frame vertically loaded in the middle of the cross bar and then only horizontally loaded in one corner. When submitted to the same load, each structure shows different deformations (for vertical load the largest deformations are for the three-hinged frame whilst they stay more or less the same when loaded horizontally).

3. To demonstrate static behavior of an arch, it is loaded vertically to show that it acts in compression whilst an interior chain (connecting the base supports) acts in tension.

4. Typical experiment for a wooden truss is setting it first without diagonals to demonstrate its instability and watch the stabilisation by inserting diagonals in each rectangular field. Students can also observe local instability occurrence when replacing some of the wooden bars with steel wires, which are further submitted to stress.

However high is their educative value, hands-on experiments are affected by complications such as a limited number of experiments, lengthy preparation and tendency of students being passive. In order to tackle these problems, some lecturers are trying to involve students in creating hands-on experiments by giving them tasks to complete, often with the support of modern software technologies.

For example, in a structural analysis course at ***London Imperial College, United Kingdom***, students are given the task of building a bridge of given length using the least material possible. The final experiment is conducted by the professor who has to walk over the student's bridge. Two prizes are awarded for the least weight and deformation solutions.

Another interesting project takes part at the ***College of Architecture in Madrid, Spain***, where students have to build a structure with small timber bars cut by themselves using only glue to join the elements.

During their structural analysis course at the ***University Jaume I de Castellon, Spain***, students are asked to build a physical model using bars and plastic joints. The whole process of creation, assembly and construction is guided by computer software SAP 2000. As described by Museros[95], first, students have to choose the type of structure to build, to evaluate its model (truss, frame, etc.) and then to sketch the new structure based on the previous one. After that, they have to prepare a physical model of the structure using plastic beams and joints. Once the small structure is built, students have to analyze it using the computer program, from which they obtain the deformed shape, the maximum displacement,

[95] MUSEROS (2002) , see also pp.348-349

normal forces and bending moment. Based on the results obtained, they improve the structure and decide which elements could be removed without influencing the overall performance. The last two steps have to be repeated until the optimum design of the structure is reached.

Another educational task gets students accustomed with a failure mechanism of balsa-wood structure (created out of a special 2 mm thick plates, which can be cut and joined with the glue). The required dimensions for the structure are: span of 1.2 m, maximum height of 1.0 m and depth of 0.3 m. The aim is to design a structure with a better ratio "ultimate load/weight of the structure". After proposing geometry, the whole structure is modeled with an ultimate load applied at midpoint and analysed with the program SAP 2000. Based on the results, modifying of the model follows (adding or deleting bars, changing section properties), resulting in final design, which they build and use for presentation, where they explain to the others the behaviour of their structure and the improvements made. Pros of the method are that it is improving students' understanding of structures, captures their interest, teaches them to work in a group and justify their ideas to plenum. On the other side, it requires considerable time to set up and material base is limited to wood and plastic whereas it would be considerable to work with materials encountered in practice (steel, aluminium, reinforced concrete). Certainly not ideal is use of a general commercial program (such as SAP 2000) designed to deal with practical engineering problems and therefore not the best choice for teaching purposes.

Students at ***ETH Zurich*** perform similar experiments using the EasyStatics program, which has been developed exclusively for educational purposes[96].

Typical example of learning by doing concept is joint project of ***Miami University*** Department of Mechanical and Manufacturing Engineering and by the Department of Mechanical Engineering at ***Carnegie Mellon University*** (a school known for its research into the cognitive science of learning) - called **"Learning Modules for Statics"** – it is a fundamental mechanics class on how objects and forces behave. The concepts are first taught entirely in the context of situations in which the forces are real to students – with the help of props such as metal rods, hooks, springs etc. they can experience the forces by the senses of touch and sight (by sensing deformation or motion). The concepts are at this stage decoupled from each other and treated sequentially, and new concepts build on those, which have already been covered. All the basic concepts of statics are addressed in this way: forces, moments, couples, static equivalency, free body diagrams, equilibrium in 2-D and 3-d, friction. Only after that are students gradually introduced to contacts between inanimate objects. Each time, the student first exerts the force by hand, prior to witnessing its application by another object (e.g., applying a non-uniform pressure to a member manually,

[96] PEDRON (2006), Easy Statics available on: http://easystatics.ethz.ch/AboutEasyStatics/E/about.html

prior to supporting it by another object). This gradual transition from manually exerted forces to contact between inanimate objects prepares students for a far sounder understanding of the loads acting at connections between bodies. The whole course is complemented by Power Point presentation explaining basic principles[97].

2.2.2 Modern software technologies

Taking the advantage of great potential offered by modern software technologies has been recognised by modern didactic studies as being conductive to learning process. Modern technology allows interactivity, simulations, animations and virtual reality, which helps students visualize abstract concepts and overall leads to better understanding of structural behaviour.

Structural design is a core subject with a centuries-old tradition. When innovative ICT tools are applied, following must be born in mind: As before, the students need to understand how the structures they design are expected to carry loads, but now they also need to know how to use the software tools they will encounter in practice. In fact, undergraduate students should first of all learn to properly model real-life structures for the computer to provide meaningful results. Then they have to learn how to extract from the computed results the information, which is relevant to structural design.

One of programs successfully run at ETH Zurich is an **Easy Statics** program developed exclusively for teaching purposes by Dipl. Bau-.Ing. Claudia Pedron between the years 2001-2006. The program is thought to be basic and fundamental 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 (2006), students can improve their understanding of structures by observing how parameters' change affects structural behavior. Interactive manipulation with the model let students compare different structural situations and make a judgement, why one design appears to be better than another.

More examples of structural analysis learning programs are: **Structural Gizmos** (Washington), **Deflect** (Glasgow) or **Grips** (Stuttgart).

[97] STEIF, DOLLAR (2005)

Second program run at ETH Zurich with positive feedback is **eQuilibrium**[98] – an interactive, graphic statics-based learning platform for structural design created by BLOCK Research Group, which development started in 2010.
The program eQuilibrium 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.
One of the team members of BLOCK Research Group, doctoral fellow Lukas Kurilla from Faculty of Architecture, CTU in Prague (architectural graduate, now PhD candidate) is currently focusing on a structurally informed form exploration process with the aim of subsequent implementation into **Donkey** - interactive structural analysis tool he has developed in cooperation with structural engineers. The goal of this tool is to help architects understand structural behaviour of their designs, to support their decision making during conceptual phases, and to guide them to improve material usage efficiency.
Computer aided teaching software can be found in many specialised areas of structural engineering. **COMPACT** (COMPuter Aided Concrete Teaching) package is latest teaching methodology, which is being used in some British Universities. It contains following modules: RC Design, Prestressed Concrete, Materials, Conceptual Design, Bridges, Foundation, Buildability and Site Practice. COMPACT is part of the Teaching and Learning Technology Programme (TLTP) for higher education in the ***United Kingdom***. Another software **CALcrete** is a comprehensive suite of 16 computer aided e-learning modules on concrete materials, design and construction. It can be effectively used as a learning tool to illustrate key concepts in the classroom or as a revision tool.

It is important to emphasize the fact that modern computer tools should in no way replace a traditional class course, but represent an appropriate supplement to it. Computer simulations can be perceived as suitable accompaniments to textbooks and face-to-face lessons. Their significance is in helping students to learn more efficiently, and review the subject outside their class.
In order to deal successfully with students' tendency to passively receive instructions, the software should implement a smart interactive way to attract students' attention and further stimulate them.

[98] eQuilibrium, available on: https://block.arch.ethz.ch/eq/

There is a widely spreading trend nowadays to use **computer-based tutoring systems** in the United States of America, where many colleges face acute financial strains, therefore administrators aim for "more productive classrooms", which are thought to be more efficient than standard face-to-face lectures. ***Miami University*** Department of Mechanical and Manufacturing Engineering is just one of them. Students do much of their coursework on Statics online before the class sessions. They have got no printed textbook, only read lessons on their laptops and watch videos on physical demonstrations. Students have assigned homework problems to solve and software records every step they take. They can opt for hints from virtual tutor if needed, so there is no time lost in waiting for the next personal contact with the teacher. Furthermore, the lecturer can see what parts were troubling students the most, and adapts the work in the classroom to it. The process is called adaptive learning. The software customizes the online material according to the individual needs, rather then offering a boilerplate set of lectures and homework to everyone regardless of how they are doing in the class. With the growing possibilities and efficiency of the modern software, it is only matter of time before it is going to be used more widely. Moreover, this system of learning requires continuous work during the term, which is more effective way of learning than otherwise typical „cramming“ before the exams. Students who are actively engaged in learning, learn more[99].

At MIT, Boston/Cambridge, the USA, they have developed accompanying computer-based tutoring system to its "graphostatics based" Form and Forces textbook on statics for architects by Waclaw Zalewski.

Not only software applications, but also **online access to a variety of study materials** can be suitable supplement to statics lessons. In comparison to classic textbooks, the data on the internet pages can be easily updated and authors have wider range of presentation tools at their disposal (e.g. video links). It might show certain level of interactivity (not as high as specialised software though) and being usually student centered they aim to develop an intuitive understanding of structural concepts.

"**Seeing and touching structural concepts"** application developed at ***University of Manchester, United Kingdom*** is a typical example. It consists of three main areas: concept explanation, physical models and examples through applications. Although originally developed for civil and structural engineering students, it is also suitable for architectural students.

Another example of interactive internet pages is **„Virtual Laboratory of Mechanics" -** site maintained by Department of Mechanics, Faculty of Civil Engineering at CTU in Prague. Apart from the lectures and self-study lessons, students can find wide variety of exercises,

[99] STEIF, DOLLAR (2005)

tests to practice and review their knowledge, details of various experiments etc. there. A section devoted to structural computing software is also a part of the whole project. Unfortunately, the pages are designated mainly for Czech students, therefore only some of the tools are available in English (selection of structural courses and short videos from You Tube, MIT Open Course Ware, ALERT Special Lectures, Introductory Structural Analysis Video Lectures, Structural Engineering on Wikiversity etc.). The advantage of pre-selection of links by university lecturers is, that the quality of the source is guaranteed[100].

2.2.3 Graphic methods

Graphic methods, popular in the 19th century, are nowadays seen by many lecturers as a way to enhance students' understanding of structural behaviour and therefore are finding their place back in the courses of Structural Analysis.

They 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. Prakash, [8]. Using these methods, forces in structures are calculated by drawing lines on paper corresponding to the magnitude and direction of the vector representing the forces. The main advantage of graphostatics is that allow designers to visualize the flow of forces throughout a given structure along with providing a direct link between structural behaviour and structural shape.

Karl Culmann (1821-1881), a pioneer of graphical methods in engineering, published a book on the subject in 1865-66. He took up a chair of engineering sciences at ETH in Zurich in 1855 and had a profound influence on a generation of engineers.

Famous professors, who put importance on graphostatics in their pedagogical approach were for example Wilhelm Ritter (1876-1956) and Pierre Lardy (1903-1958), both from ETH, Zurich. According to Gauvreau (2005), both professors put great emphasis as well on the description and critical discussion concerning the real structures, structural systems and detailing. Students observed structural system and its behaviour in close link with aestethic aspects of design. Both professors believed that structural knowledge gained through the thorough analysis enables students design quality structures of their own. Ritter and Lardy regarded structural analysis as a tool serving the needs of design rather than end in itself.

Among students of Ritter and Lardy were widely recognised great designers of the 20th century Robert Maillard (1872-1940), Othmar Ammann (1879-1965), Heinz Isler (1926-

[100] Virtual laboratory of Mechanics, available on:
http://mech.fsv.cvut.cz/wiki/index.php/Virtuáln%C3%AD_laboratoř_mechaniky

2009) and Christian Menn (1927-). Most people see their achievements as a compelling evidence of the power of education to influence the practice of structural design.
When the computer revolution of the last few decades is atken into account, a field of the structural analysis is no exception. Using programmable computers led to the fundamental changes in the work of the structural engineers. Structural analysis is done by computer programs, and that further requires a cooperation between structural engineers and program developers who are no specialist in the field of the building structures. A deep knowledge of structures is therefore needed to operate such programs. The understanding of how the structures behave is very important even for an architect who wants to create a functional design, and for this purpose graphical methods suit perfectly, despite being seen as of little relevance when compared to the possibilities of a computational outputs available.
Contemporary advocate for graphostatics methods for lecturing on structures is the team of Karl-Eugen Kurrer, 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.
At MIT Boston/Cambridge, USA, graphostatics methods in teaching statics to architects were revived by Waclaw Zalewski and Edward Allen, and are being successfully developed by John Ochsendorf.

Results

- Two main streams in educating Structural Engineering to future architects are represented by traditional teacher-centered instructional and behaviourist approach and more recent student-centered instructional and constructivist approach
- Innovative methods currently used at some other European/world faculties of architecture can be divided into three groups: hands-on experiments, use of the modern software, graphic methods

Evaluating hypotheses and conclusions

- Final conclusion on the hypothesis H5 (innovative methods are more appropriate for teaching SE to architectural students than traditional frontal teaching methods) cannot be made at the current stage of the research, but according to the own classroom observations, students of architecture are accustomed to learn in visual, creative way, therefore student-centered instruction and constructivism approach seems to be more beneficial for them. Typical example of this method is participating in guided interactive manipulation with models, which improves critical thinking, understanding of the structure and it supports the development of an intuitive design of a structure.

Focused study on Visual Statics course - newly introduced seminar at Faculty of Architecture, CTU in Prague

„Structural Engineering in Architectural Studies at CTU Prague“
(New ways of teaching Structural Engineering at CTU Prague and its share in curricula compared to selected European faculties of architecture)[101]

Specific objectives:

- to describe SE in curricula of architectural students at CTU in Prague
- to assess Visual Statics course newly introduced to curricula at CTU in Prague

Results:

Newly introduced Visual Statics Course at Faculty of Architecture, CTU in Prague:

- based on Graphic Statics
- currently consists of six seminars analyzing principles of static behavior for five types of isostatic plane structures
- a short introduction on elementary theory describing static behavior of related structures is closely followed by "hands-on" experiments

Reasons for initiating the course

According to the own experience of my colleagues, students entering architecture at CTU in Prague show overall weak bases in technical subjects knowledge, which consequently leads to the need of modifying current courses on structural mechanics[102]. It is generally thought that after finishing structural mechanics course, deepening and strengthening of gained knowledge together with adapting its basic principles would be beneficial before entering subsequent course on load-bearing structures. Visual statics (which has been introduced and run tested at the Faculty of Architecture at Czech Technical University in Prague in winter term 2014/2015 as a voluntary supplement course to a current block of Structural Engineering subjects featured in curricula) course's target is to help the students redintegrate their knowledge of theoretical mechanics. The aim of the pilot course 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,

[101] POSPISIL, VAVRUSKOVA (2016/2)
[102] POSPISIL, VAVRUSKOVA, VERTATOVA (2014)

especially the geometry of structure are in the hands of architects – that is why architects should be familiar with the relationship between the geometry of structure and its load carrying capacity.

Introductory part of the course – general context

The introductory part of the seminar reviews student's knowledge on load-bearing structures. The emphasis is put on the principles and static behavior of certain type of the structure, but other important facts are looked at as well (e.g. the types of structure loading and load carrying capacity of particular material). A role of an architect is also discussed in context with designing geometry of a structure.

Next section of the seminar is devoted to the historical development of structural design. From "proportion rules" featured in the Old Testament, through "geometric rules" typical for medieval ages, concept of strength of material and theory of elasticity in the 17th century, calculation methods replaced by graphical analysis, plasticity theory, deformation method and finally Finite Element Method, it cuts the wide swath.

Introductory part of the course – graphic statics principles

Then basic terminology of graphic statics is explained. Forces are represented by a line in magnitude and direction and can be either concurrent (meeting at common point), non-concurrent (do not coincide at common point) or parallel.

Students learn how to draw coplanar forces (lying in one plane) in scale and direction. After basic principles of graphic statics are explained (see bellow), students use gained knowledge to solve show cases with the help of graphic statics under the guidance.

Karl Culmann (1821-1881), a pioneer of graphical methods in engineering, published a book on the subject of Graphic Statics in 1865-66. Using the method had a profound influence on a generation of engineers. Following summary of its basic principles is taken from the textbook by Prof. Prakash Rao[103].

1. The resultant of two coplanar non-parallel forces is given by the diagonal of the parallelogram drawn with the two forces as the adjacent sides.

2. If two coplanar forces are drawn to some scale head to tail, the line connecting the free ends of the forces represents the resultant of the forces.

3. If the direction of resultant is reversed, it forms a triangle (closed loop) and the forces are in equilibrium – the principle of the triangle of forces.

4. The concept of a force triangle can be extended to any number of concurrent forces, which form force polygon. Forces are in equilibrium when polygon is closed. When polygon is not closed, the closing side represents the resultant of force system.

[103] PRAKASH (1997)

5. Any force can be randomly split into components providing they have the same effect on the body as the original force. Force is split with the help of an arbitrary point „O“ - pole.
6. Magnitude and direction of a resultant of a system of non-concurrent coplanar forces can be determined the same way as for concurrent forces from force polygon, however to get its location we must use a polar diagram. First we choose the pole and split the forces, then we draw a polygon in the force system with the help of arbitrary points and lines parallel with rays from polar diagram. Resultant is located at the intersection of extended lines of action of the outer (first and last) force components (the inner components cancel each other).
7. The polygon formed by the rays of the polar diagram is known as the link polygon. Since it represents the deformed profile of a flexible rope, fixed at its ends and under the action of given forces, it is also known as string or funicular (rope like) polygon.
A string assumes the profile of a series of straight segments with the nodes at the concentrated loads. In the case of distributed loading on the string, it assumes a smooth curved profile.
It is also shown how the principles of equilibrium conditions can be extended to the analysis of determinate trusses, which consists of resolving member forces. The members of a truss are subjected only to axial forces and they can be obtained by applying the principles of the force polygon successively at each joint. Force polygons for trusses are called Maxwell-Cremona diagrams (also referred as stress diagrams).

Running the course

The Visual Statics course (Structural Mechanics seminar), which is based on Graphic Statics, currently consists of six seminars analyzing principles of static behavior for five types of isostatic plane structures.
At the beginning of each seminar, there is a short introduction on elementary theory describing static behavior of related structures, closely followed by “hands-on” experiments. Physical model of particular structure is build, then gradually loaded with weights. In the process, internal forces on selected parts are measured with the help of force transducers. Then, appropriate virtual computer-aided model is created with loading simulation to verify the experiment. Calculation is completed by structural assessment using graphic statics. Teaching aid for above described activities comprises of: board for demonstration, building set for creating the truss structures (rods, joints, tackles), nylon cables, weights and force transducers.

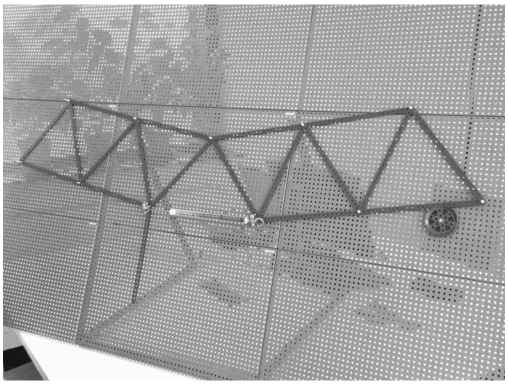
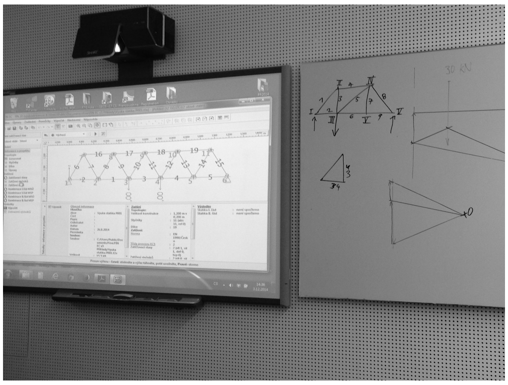
 

Fig. C2.1 CTU Visual Statics lectures / Measuring internal forces on a model simulation on a virtual computer/aided model (left)

Fig. C2.2 CTU Visual Statics lectures/ Verification of the experiment by loading (right)

Course assessment, hypotheses evaluation, conclusions

- in mz opinion, **it is important to get the architectural students feel what is and what is not structurally possible when creating a design**
- although traditional curricula comprises of all the necessary knowledge on SE architectural students need to be accustomed with, in my experience, **only part of them really understands the problematics**
- the methods used at some top faculties of architecture (e.g. ETH Zurich, Switzerland) have been looked into in order to find the form of lecturing with proven academic success, which would simultaneously catch students' attention
- as far as hypothesis **H5** is concerned (innovative methods of teaching SE to architectural students are more appropriate), I cannot agree to the full extent;
  in my opinion, **hands-on experiments are of a great didactic value and indisputably apt especially for architectural students** (who are predisposed to learn in a visual – creative way), however I would consider conducting them without any “technical” base knowledge already gained (by frontal methods of teaching) as more complex to carry out, therefore **I would not choose to employ them solemnly, but opt for using them only as a supplement** to the current courses
- optimal placing of Visual Statics in our case would be after introductory mechanics courses and before subsequent courses on Load-bearing Structures
- targetted outcome of the course on Visual Statics (which was tested at Faculty of Architecture, CTU in Prague, in winter term 2014/15) is to boost students’ understanding of basic static principles
- the course was received positively by its participants

- whilst test-running the Visual Statics course, observations and dealing with arisen practical situations provided valuable feedback; the original course was consequently fine-tuned and is going to be offered as a voluntary supplement to the regular part of a curricula from now on

Pilot study on aims and content of SE courses

"Aims and Content of Structural Engineering Courses
in Architectural Studies at Selected European Universities"
(Comparative study for CTU in Prague, Czech Republic, the University of Bath, United Kingdom and the University of Stuttgart, Germany)[104]

Specific objective:

- to analyze and compare aims, content and targeted skills of Structural Engineering subjects at selected European architectural schools and courses

Selection criteria:

- Study plans of the following universities were used for the analysis:

  The Czech Technical University in Prague
  (conducting the research)

  The University of Bath, England
  (representing English speaking universities)

  The University of Stuttgart, Germany
  (representing German speaking universities)

Selected courses:

Both University of Bath and the Czech Technical University offer two main course specialisations: Architectural Design and Architectural Engineering. These were taken for closer examination. The University of Stuttgart does not offer Architectural Engineering course as such, but there is an option of choosing a Civil Engineering specialisation, which makes it comparable with the rest of the sample. With the exception of Architectural Engineering course at University of Bath (which is not offered in bachelor version and is classified as master despite its length of 4 years compared to usual "4 bachelor + 2 master follow up" scheme), only bachelor courses were analysed, as it has been previously found out

[104] POSPISIL, VAVRUSKOVA (2016/1)

in Pospisil and Vavruskova (2014), that the share of SE subjects in "master follow up studies" of architectural courses'curricula does not usually exceed 5%.

Supplementary information on courses' length

The length of the bachelor courses is either three or four years as follows:
CTU Architecture (CZ AD) – 3 years
CTU Architectural Engineering (CZ AE) – 4 years
University of Bath Architecture (UK AD) – 4 years including a half year long professional placement
University of Bath Architectural Engineering (UK AE) (exception – classified as master – see explanation above) - 4 years without professional placement, 5 years including 1 year long professional placement
University of Stuttgart Architecture (GE AD) – until 2015/2016 – 4 years, since 2015/2016 – 3 years
University of Stuttgart Architecture with Civil Engineering specialisation (GE AE) - until 2015/2016 – 4 years, since 2015/2016 – 3 years

Results:
Structural Engineering Courses at selected European Faculties of Architecture

Introductory Structural Engineering course

After thorough and detailed examination of all selected study plans, a conclusion has been made that introductory course on Structural Engineering has almost identical form in Germany and England (where it is called "Structures"), whether it is designated for Architectural Design (AD) or Architectural Engineering (AE) students.
Students learn about structural mechanisms, Newton's laws, static equilibrium and free body diagrams. It is followed by the concepts of forces and moments in structural members, equilibrium of loads and forces and moments in simple structures. Courses look into the load carrying action of trusses, beams, arches, cables and columns. Explained are also concepts of stress, section sizes and shapes, followed by focus on pin-jointed trusses (including triangles of forces, resolving at joints and method of sections; physical behaviour and structural form and efficiency). Next in the curricula are direct stresses and strains (together with Young's Modulus), followed by beams and free body diagrams, bending moments and shear forces. Bending stresses in beams, section shape and structural efficiency are also explained, as well as the concept of shear stresses. English curricula contain also stability concepts, which are in other countries explained in later stages, or hanging chains, funicular shapes and simple

suspension systems, which other countries do not focus on. Three pin arches and goal-post portal frames are included in curricula of all of the selected universities.
As far as the introductory courses of SE at CTU are concerned, they are called “Statics” (CZ A) resp. “Structural Mechanics” (CZ AE) and despite having almost identical content, their main focus lays in the theoretical explanation of basic structural behaviour (e.g. laboratory demonstrations are not part of the course). To compare with British curricula, basic dimensioning of structural members is not taught until later stages as well as introduction to structural materials (in the 4th semester at CZ A).
The courses run in the first semester at University of Bath (evaluated 6 ECTS), in the first and second semesters at University of Stuttgart (evaluated 6 + 6 ECTS) and in the second semester at the Czech Technical University (5 ECTS for AE, 3 ECTS for AD).
The main aims of the course are as follows: to familiarise students with different types of structural materials (with the exception of CZ A) and assemblies, to introduce the concepts of statics and load carrying mechanisms, sufficient for an elementary appraisal of structures (again in later stages at CTU) and to make students aware of the role played by structure in the design and building process.
After successfully passing the course, students should be able to design a simple structure and identify and calculate the forces within it. The main skill they should gain is an ability to analyze statically determinate structures and to apply statics principles in the context of a design problem.

Follow-up Structural Engineering courses

Understandably, the differentiation of SE courses in relation to the students’ specialisation (AD vs. AE) can be observed almost immediately after the introductory part. AE students continue with further and more complex chapters from SE, whilst AD students concentrate on practical aspects of the basic structural design. The exception is CZ A, where for one term students first „catch up“ (cca 30% of German/English introductory SE curricula is explained later at CTU) and then continue with further SE topics covered in other cases by AE curricula such as: centroid, neutral axis, section modulus, moment/curvature relations and analysis of deflections, shear flow in beams, torsion of thin/walled closed sections, shear centre; torsion of thin/walled open sections or Euler buckling load for columns; differing end constrains; imperfections, eccentric loading and initial curvatures.
The main aim of the lecture is to introduce students to the internal action of structures, stresses and strains. The gathered skill should be an ability to analyze stress, strain, deformations and stability in simple structures.

The typical AE curricula (usually in the third and in the fourth semester of study) further covers various topics from SE such as: aproximate analysis of statically indeterminate structures, virtual work and the Unit Load method for calculating deflections, flexibility analysis of statically indeterminate truss and frame structures, lack of fit, support settlements, temperature effects, virtual work extended to beams subject to bending, shear and torsion, torsional and shear deflection of beams, derivation of slope deflection relations, application of the slope/deflection method to continuous beams and sway frames, FEM methods, use of numerical methods for structural analysis – for elastic structures, and plastic analysis of structures including multibay frames and the yield line analysis of slabs.
English AE curricula also contains chapters from vibrations, turbulence, aerodynamics and earthquake in the later stages of studies.
Individual courses at University of Stuttgart are allocated to one of the three moduls: Base Modul (compulsory), Core Modul (containing projects) and Complementary Modul, which is further divided into five areas. There is a particular amount of ECTS credits set for each area, which can be distributed variably according to the chosen professional specialisation. This gives the students oportunity to specialize in Architectural Engineering.

Introduction into the Building Constructions

With the exception of CZ A (where the basic introduction into the building constructions, structural materials and basic concept of structural design – such as the definition and quantification of loads on structures and concepts of safety, stability and serviceability - are explained at the 4th semester), all other study programmes run it either simultaneously with the introductory SE course (CZ AE, GE A, GE AE at the 1st semester) or the following semester (UK A, UK AE). It gives the students basic information on loadbearing structures, foundations, masonry, timber structures, concrete structures and (with the exception of CZ A where it is covered later) steel structures. German curricula devotes the topic the most time and covers additional fields like façade engineering etc.
The main aim of these courses is to introduce the students to the basic general information about the building structures, building materials and designing process.

Detailed structural design & Design Studio

In each study programme, there is a time devoted to the detailed structural design. Structural design is also an important part of the studio design, which takes part throughout the whole study and grades with a coherent building proposal resolved at all levels in the final year of the study for all analysed study programmes.

At University of Bath students start with the design of a simple timber structure using frame construction in the first semester, followed by the design of a single storey steel structure building and at least two storeys high family house (masonry) in the second semester. Design of steel and reinforced concrete structural members is a part of SE course in the third semester as well as the design of connectives. Students may take Erasmus exchange semester in the third year and the city they stay in becomes the setting for their individual design project at that time.

At CTU, detailed structural design for AD students is taught in series of following courses: masonry and concrete in the fourth semester, reinforced concrete in the fifth semester, timber and steel in the sixth semester. Detailed foundations design is only available for the students continuing in master studies. AE students at CTU have foundations design in the fourth semester, concrete design (incl. reinforced and pre-stressed) in the fifth and the sixth semesters, and steel and timber design in the sixth and the seventh semesters. They also have continuous lectures on the building structures throughout the whole length of their study.

The largest volume of the detailed structural design courses is offered by the University of Stuttgart in Germany, however it depends on the personal choice of each student, whether they decide to specialize in Structural Engineering.

Other related courses/ activities

For all European universities, there is a possibility for students to participate in Erasmus exchange programme, which usually takes part in the third or in the fourth year of their studies and lasts one or two semesters.

At the University of Bath, students take half year long professional placement in the fourth semester and in order to develop creative collaborative working between architects and engineers, team design takes part in the sixth semester. A series of lectures is also given by invited practising engineers, covering a set of topical, innovative structural engineering case studies.

As already mentioned, the voluntary supplement course of Visual Statics has been recently introduced for AD students at CTU[105].

Further specialisation / Specialised areas of interest

At the University of Bath, AE students take in their final years of study specialised courses on Geotechnical, Bridge, Coastal and Façade Engineering and have further options of enrolling into various supplement courses such as Advanced Timber or Materials Engineering in construction courses.

[105] Visual Statics at CTU Prague, see pp.76-80

As already mentioned, students at the University of Stuttgart benefit from courses' "Modul" system, which enables them to create their individual specialised study plan. There is also the possibility of a professional placement, which takes six months.

Forming/evaluating hypotheses, conclusions

- After analysing **Structural Engineering courses for bachelor studies** (including both Architectural Design and Architectural Engineering specialisation) at three selected European faculties of architecture (**CTU in Prague in the Czech Republic, the University of Bath in United Kingdom and the University of Stuttgart in Germany**), a conclusion has been made that due to the long-term development and constant adjustment to the requirements of the current workplace, **the aims, content and targeted skills** (when considering similar types of course)of the courses **are almost identical**. Hypothesis H4 (presuming wider range of SE topics in curricula of German and English universities) was therefore refuted.
- Students should **get familiar with different types of structural materials**, with **basic statics principles**, and with the **concepts of structural design.** They should be able to **apply the knowledge in the context of a design problem**.
- What **differs slightly is the position of courses with the similar content in the curricula's timetable,** however within the means of logical sequencing (detailed analysis is presented in the form of a table as seen on Fig.C2.3[106]).

There is however one important fact, which in my opinion puts the students of Architectural Design at CTU in Prague compared to other analysed universities to a certain disadvantage. The previous analysis showed the value of the share of SE subjects in curricula at CTU (AD) as 8.33 %, which seems to be underrepresented in the context of 27 selected leading English and German universities, where the share ranges between 10-15 % (English) resp. 15-25 % (German). **English and German students seem to have an advantage of more thorough and detailed training** in order to adapt the skills needed for creating an effective design of the structure.

- Furthermore it seems that **English and German students benefit** from incorporating **innovative methods** of teaching into the learning process (e.g. hands-on experiments), **guided cooperation seminars with civil engineering students** and compulsory **work placement** as a part of their bachelor courses.

[106] see the attachment in the pocket

Note: Following table is intended for e-version only. For the actual reading, please see the attached A3 size printed table in the pocket of the thesis.

Time frame (divided into semesters)→	SEM 1					SEM 2					SEM 3					SEM 4					SEM 5					SEM 6					SEM 7					SEM 8				
AREA OF CURRICULA/ topic specification ↓	UK A	UK AE	CZ A	CZ AE	GE A	UK A	UK AE	CZ A	CZ AE	GE A	UK A	UK AE	CZ A	CZ AE	GE A	UK A	UK AE	CZ A	CZ AE	GE A	UK A	UK AE	CZ A	CZ AE	GE A	UK A	UK AE	CZ A	CZ AE	GE A	UK A	UK AE	N/A	CZ AE	N/A	UK A	UK AE	N/A	CZ AE	N/A
BASIC INTRODUCTION INTO CONSTRUCTIONS																																								
Loadbearing structures				■	■	■	■			■								■																						
Foundations				■	■	■	■			■								■																						
Roofs				■	■	■	■			■																														
Masonry				■	■	■	■			■								■																						
Timber structures				■	■	■	■			■																														
Concrete structures (incl. reinforced & pre-stressed)				■	■	■	■			■								■																						
Steel structures				■	■	■	■			■																														
STATICS & MECHANICS																																								
Structural mechanisms	■	■			■			■	■	■																														
Newton's laws, static equilibrium, free body diagrams	■	■			■			■	■	■																														
Forces and moments in structural members	■	■			■			■	■	■																														
Equilibrium of loads, forces and moments in simple structures	■	■			■			■	■	■																														
Load carrying action on beams	■	■			■			■	■	■																														
Load carrying action on trusses	■	■			■			■	■	■																														
Load carrying action on arches, cables and columns	■	■			■					■																														
Pinjointed trusses	■	■			■			■	■	■																														
Direct stresses and strains	■	■			■			■	■	■																														
Young's modulus, elastic behaviour	■	■			■		■		■	■																														
Beams and free body diagrams, bending moments and shear forces	■	■			■			■	■	■																														
Internal stress equilibrium	■	■			■		■	■		■			■	■																										
Mohr's circle for stresses and strains; principal stresses and strains							■						■	■																										
Bending stresses in beams, section shape and structural efficiency	■	■			■		■			■			■	■																										
Concept of shear stresses	■	■					■	■						■																										
Overal efficiency of beams and simple bridges	■	■												■																										
Stability concepts	■	■											■	■																										
Hanging chains and funicular shapes; simple susspension systems	■	■																																						
Three pin arches and goal-post portal frames	■	■						■											■																					
Centroid, neutral axis, section modulus							■	■	■																															
Second moment of area							■	■	■																															
moment/curvature relations and analysis of deflections							■							■									■																	
shear flow in beams							■	■						■																										
fabricated and composite beams													■																											
bending of assymetric sections							■							■																										
torsion of thin/walled closed sections							■	■						■																										
shear centre; torsion of thin/walled open sections							■	■						■																										
stresses due to combined bi[axial bending, torsion and axial loading in structural members							■						■	■																										
Euler buckling load for columns; differing end constrains; imperfections, eccentric loading and initial curvatures							■						■	■																										
Statics for statically determinate frames and trusses								■	■			■																												
Aproximate analysis of statically indeterminate structures												■							■																					
Virtual work and the Unit Load method for calculating deflections												■							■																					
Flexibility analysis of statically indeterminate truss and frame structures												■							■																					
Lack of fit, support settlements												■							■																					
temperature effects								■				■							■																					
Virtual work extended to beams subject to bending, shear and torsion												■							■																					
Torsional and shear deflection of beams								■				■							■																					
Derivation of slope deflection relations												■							■																					
Application of the slope/deflection method to continuous beams and sway frames												■							■																					
Moment distribution												■							■																					
FEM methods, use numerical methods for structural analysis – for elastic structures																			■			■																		
Plastic analysis of structures incl. Multibay frames and the yield line analysis of slabs																			■			■																		
vibrations																																■								
torsional buckling																			■													■								
turbulence, aerodynamics																																■								
earthquake																																■								
SOIL MECHANICS																	■		■																					
STRUCTURAL MATERIALS				■	■					■	■	■						■																						
STRUCTURAL DESIGN																																								
The structural design proces				■	■					■	■	■						■																						
Basic concepts of static and structural action				■	■					■	■	■						■																						
Definition and quantification of loaads on structures				■	■					■	■	■						■																						
Concepts of safety, stability and serviceability				■	■					■	■	■						■																						
Design of steel structural elements					■					■	■																	■	■					■						
Design of reinforced concrete structural elements					■					■	■												■	■					■											
Design of connections					■			■		■	■																													
Design of timber structural elements					■					■																		■	■					■						
Design of masonry structural elements					■					■				■				■																						
Foundations design					■					■									■															■						
DESIGN STUDIO	ALL STUDY PROGRAMMES THROUGHOUT THE WHOLE STUDY																																							
TEAM DESIGN collaborative working with engineers																						■									■									
PROFESSIONAL PLACEMENT																■						■				■	■													
COHERENT BUILDING PROPOSAL resolved at all levels	ALL STUDY PROGRAMMES IN THE LAST SEMESTER																																							
SPECIAL AREAS OF INTEREST																																								
Geotechnical Engineering																						■																		
Coastal Engineering																											■													
Bridge Engineering																											■													
Facade Engineering					■					■									■								■													

LEGEND

UNITED KINGDOM
University of Bath

UK A Architecture
UK AE Architectural Engineering

CZECH REPUBLIC
Czech Technical University in Prague

CZ A Architecture
CZ AE Architectural Engineering

GERMANY
University of Stuttgart

GE A Architecture

Fig. C2.3 Structural Engineering topics in bachelor curricula at selected European universities

(CTU in Prague, Czech Republic
The University of Stuttgart, Germany
The University of Bath, UK)

Qualitative and quantitative research summary

Structural Engineering **appears to be an important** part of architectural curricula at all European universities, especially for the bachelor courses. That said **share of Structural Engineering on architectural curricula varies considerably** among the analysed universities, **ranging between 5-42% in bachelor courses and 0-45% in master courses**. This among others depends on whether the courses are offered as 'pure' Architectural Design on one hand or Architectural Engineering (possibly Architectural Design with specialisation on Structural Engineering) on the other. **German speaking and the top rated UK universities tend to have higher than average share of Structural Engineering** in their architectural curricula. **In bachelor studies,** Structural Engineering represents **around 35% of curricula at leading British universities and at architectural engineering combined courses. Most English-speaking European universities have 10-15%** of Structural Engineering in their curricula. **German speaking European universities** (Germany, Austria, Switzerland) **show overall higher volume of Structural Engineering** in their courses, **which varies between 15-25%. For majority master** architectural courses, Structural Engineering subjects represent **up to 5%** of curricula. Some universities offer **further specialisation** in Structural Engineering, which **boosts** share of Structural Engineering subjects in their curricula **to 10-45%**. Finally, **with 8.33% share in bachelor studies, Structural Engineering subjects at the Faculty of Architecture, Czech Technical University in Prague, seem to be underrepresented in context** of the above-mentioned European universities, where such share most typically ranges between 10-25%. Share of Structural Engineering on architectural curricula at The Czech Technical University is also low in curricula of the Architectural Engineering bachelors and master courses provided by the Faculty of Civil Engineering in comparison with similar European Architectural Engineering or Architectural Design courses with specialisation on Structural Engineering.

Following hypotheses were formed and evaluated within the research:

H1

The percentual share of SE subjects in bachelor architectural curricula of German universities from the selection is higher compared to other European universities.

Partly verified

The share of SE subjects at selected German speaking (Germany, Austria, Switzerland) varies typically between 15-25%, whilst most English speaking universities have only 10-15% of SE subjects in their bachelor architectural curricula. The sample consisted of 27 selected European English (12) and German (15) speaking universities. The exception represent two top rated British universities from the selection (University of Cambridge and University College of London), where the percentual share is approx. 35 % of curricula, which is comparable to curriculas of combined Structural Engineering courses.
For details see the "Follow up quantitative study" results.[107]

H2

The share of Structural Engineering subjects at in bachelor architectural courses at Faculty of Architecture, CTU in Prague is underrepresented in context to other selected European English and German universities.

Verified

The share of SE subjects in bachelor architectural curricula at FA CTU (Architectural Design) in Prague is 8.33%, which seems to be underrepresented in context of other selected German and English speaking European universities from the research.
It was furthermore shown that the share of SE in the bachelor curricula of combined Structural Engineering course at CTU in Prague is with its 15% also lower in comparison to similar courses at selected European German and English universities, where the typical range is around 35%.
For details see chapter the "Follow up quantitative study" results.[108]

H3

Volume of Structural Engineering subjects in architectural curricula is on comparable levels for selected major Czech (and potentially Slovak – because of joint history as Czechoslovakia in the years 1918-1992) technical universities.

Verified

Conducted research has shown, that typical share of SE subjects in bachelor Architectural Design curricula is in the range of 5-8% for all selected Czech and Slovak technical universities.

[107] Follow up quantitative study results pp.52-54
[108] dtto

For Architectural Engineering bachelor curricula it has shown the value of approx. 15%.
For details see the "Supplementary quantitative study" results.[109]

H4

Having allocated more time to Structural Engineering in their bachelor architectural curricula, students at German and the top rated British universities are taught wider range of SE topics than students at other European faculties of architecture from the selection.

Refuted

Study plans of selected representantives of German (University of Stuttgart) and British (University of Bath) universities were submitted to thorough and detailed analysis into the aims, targetted skills and content of their bachelor architectural courses as far as SE subjects are concerned. In the previous analysis (comparing the share of SE subjects in bachelor architectural curricula) bigger volume of SE subjects for English and German universities compared to this of CTU was shown, therefore it was assumed that the wider range of SE topics is beeing taught at these schools. The assumption has proved wrong, all the universities from the sample have comparable content of SE courses. Students should get familiar with different types of structural materials, with basic statics principles, and with the concepts of structural design. They should be able to apply the knowledge in the context of a design problem.Therefore I think, that English and German students seem to have an advantage of more thorough and detailed training in order to adapt the skills needed for creating an effective design of the structure. Furthermore it seems that English and German students benefit from incorporating innovative methods of teaching into the learning process (e.g. hands-on experiments), guided cooperation seminars with civil engineering students and compulsory work placement as a part of their bachelor courses.
For details see the qualitative "Pilot study on aims and content of SE courses" results.[110]

H5

Innovative teaching methods are more appropriate for teaching SE subjects to architectural students than traditional frontal methods.

Partly verified, with reservations

[109] see p.58
[110] see pp. 81-85

Students of architecture are accustomed to learn in visual, creative way, therefore student-centered instruction and constructivism approach seems to be more beneficial for them. Typical example of this method is participating in guided interactive manipulation with models, which improves critical thinking, understanding of the structure and it supports the development of an intuitive design of a structure.
As far as the preferable use of innovative teaching methods is concerned I would not agree to the full extent; in my opinion, hands-on experiments are of a great didactic value and indisputably apt especially for architectural students (who are predisposed to learn in a visual – creative way), however I would consider conducting them without any “technical” base knowledge already gained (by frontal methods of teaching) as more complex to carry out. Therefore I would not recommend to employ them solemnly, but opt for using them only as a supplement to the current courses.

Qualitative and quantitative research conclusion

As observed by many tutors of Structural Engineering,[111] and in accordance with my own observations from the CTU in Prague, teaching structural analysis to architectural students brings to attention following attributes that would be appropriate to address: lack of motivation to learn structural analysis, lack of interest to understand how the structures work, routine and often incorrect application of mathematical formulas. In the opinion of educational specialists (e.g. Orlich, Kalhous, Obst, Pecina, Zormanova, Skalkova, Rohlikova, Vejvodova, Kasikova, Okon, Petty, Conway), traditional teacher-centered tuition puts students into the roles of passive recipients and compared to alternative methods of lecturing (e.g. “learning by doing” or using specialised software) it appears to be less effective. Student-centered instructional and constructivist approach furthermore strengthens students’ independent thinking, improves their communication and reasoning skills and prepares them for teamwork.

In this research, I would like to focus on opportunities to supplement the current Structural Engineering lectures to architects at the CTU through innovative methods. In my opinion, traditional approach to lecturing, which has been formed over many years as a reflection of development of scientific thinking, cannot be entirely disregarded. Critical thinking of students needs to be improved together with their understanding of the structure and ability to

[111] e.g. PEDRON (2006), VRONTISSI et al. (2017), YAZICI (2013), TOMOVIC (2018), SOTO-RUBIO (2017), LONMANN (2001), KHODADADI (2015)...

solve the real-life problems, however I think, that what students need the most is a solid "technical knowledge base", which is in my opinion best obtained through traditional way of lecturing. On this base they can further build up their expertise with the help of highly illustrative interactive teaching methos. I think that this may be achieved by introducing a course of Visual Statics to the curricula, preferably after the block of Structural Mechanics and before the block of Load-bearing Structures.

Unfortunately, at the present time it seems that architectural students at CTU in Prague are put into a slight disadvantage compared to students from English and German universities from the selection due to relatively low volume of 8.33 % SE subjects in their curricula. Detailed analysis of study plans has shown the content of the courses being of a similar character, therefore students at German and English European universities have more time to comprehend targeted skills needed for creating an effective design of the structure. Compared to the CTU students, they seem to further benefit from guided cooperation seminars with civil engineering students and compulsory work placement as a part of their bachelor courses.

When comparing an efficiency of the teaching process at CTU vs. at the other universities, a significantly lower budget per student, which is currently at the disposal of CTU in Prague must not be forgotten to be mentioned (e.g. twenty times lower compared to ETH Zurich and even more pronounced in comparison to MIT Boston).

D SYNTHETIC PART

D1 CRITICAL EVALUATION

CRITICAL EVALUATION OF APPROACHES TO ARCH. SE TEACHING / SCHOOLS GROUPING

During the process of the actual analysis, I have noticed that two main approaches to SE concept in architectural curricula can be distinguished: Teacher-Centered Instructional and Behaviourist and Student-Centered Instructional and Constructivist. The topic was researched in the focused "Follow up study on teaching methods"[112].
Each of the main groups displays varieties within, as further mentioned.

For the purpose of the study, I have decided to organize the schools from the survey (the main case studies[113] and the case studies from the conference papers[114]) by creating the **main grouping** (according to the general approach to teaching SE to architects), and the **secondary grouping** (according to the selected features relevant to the SE architectural education).

[112] see pp 66-75 follow up on teaching
[113] see chapter G1.3, pp.237-335
[114] see chapter G2, pp.337-359

The main grouping of schools from this research

(according to the general approach to teaching SE to architectural students)

Particular **schools** have been **allocated to typological groups** on the basis of the analysis of their study plans, and on the basis of a research into the textbooks and other materials the lecturers use for SE courses.

The cases where certain type of **different attitude** to teaching/learning (e.g. graphostatics methods in predominantly scientific attitude environment or recommended "classical" structural educational books as a supplement to purely graphic statics attitude) was present **on general/introductory/ supplementary basis only**, were classified according to the dominant feature of the overall system (e.g. at the **CTU in Prague**, where the principles of graphic statics are introduced to students in the form of a lecture within the introductory Statics course, and students subsequently practice the method on the real practical tasks during the exercises such as drawing force paralellograms, getting forces on a beam etc.). Students are also trained how to get these features in a traditional way in order to compare both methods. At the current time, the overall attitude to dimensioning structural parts is by the means of a scientific calculating. Another example of classification based on predominant features is **HCU Hamburg**, where at the beginning of the second structural course, 2 lectures and two exercises are devoted to graphic statics).

GROUP 1A
DETAILED
SCIENTIFIC/ TECHNICAL/ ANGLO-SAXON ATTITUDE

As already noted, this type of teaching/learning **reflects the development of scientific thinking**, leading to employing sophisticated mathematical models in the process.

The **representants** of schools from the sample are as follows: ABK Stuttgart, HCU Hamburg, RWTH Aachen, TU Munich, UDK Berlin, University of Bath, and CTU Prague.
The schools from the sample use the methods of **exact calculations**, however most of them get the students acquainted also with the possibilities of **empirical design** methods[115], used especially in a professional praxis.

[115] see group 1B , pp.95-98

On the basis of own observations, I can generally confirm, that **the actual depth of the course** (i.e. to what extent particular topics are studied/ discussed and corresponding skills (actual designing) are practiced within the course) closely **correlates with the number of allocated credits to the subject**. I was questioning myself whether I found some exceptions reflexing an advanced utilisation of a certain allocated time to the topic within the curricula, but unfortunately did not come across any such an example. The other question is an actual benefit from a broader structural concept within the architectural curricula, an answer to which an opinion is going to be expressed on in this work's summary.

The **traditional attitude does not mean** the school is **not following up-to date trends** in teaching/learning (as can be seen on many examples of various "innovative" activities that take place within the traditonal curriculum).[116]

GROUP 1B
MORE PRACTICALLY ORIENTED
SCIENTIFIC/ TECHNICAL/ ANGLO-SAXON ATTITUDE

Scientific attitude represents the basis of structural design in this group as well, however the students usually perform less strenuous calculations and devote more time e.g. to various verbal analyses based on observing.

The **representants** of schools from the sample are as follows: UCL London, University of Edinburgh, University of Nottingham.

I would like to give an example of the renowned **Bartlett School of Architecture at UCL London**. Ms Katarina Krajciova has explained the school's attitude to structural design how she has experienced it whilst studying there: according to her words, the empasis is put onto the studio work (awarded at least half of the total year's credits, represented by "smaller" scale project submitted before Christmas, and following loosely connected "large" project the result of which is the design of a building. Technical subject is only one each year. In the first year, it is not connected with the studio work (instead of it, students make an analysis of a building from pre-selected list, the analysis need not to be strictly structural). In the second year, students work on a structural design connected with their studio work, and although this pre-set repeats in the third year, the importance of a structural design in the final year is

[116] see the introduction , p.93, 2nd paragraph

represented by the fact that structural design is awarded twice more credits compared to the second year.

More practically oriented attitude is also very often practiced at schools with reduced time allocation to the subject compared to schools from group 1A. Here I can name e.g. **University of Edinburgh**, where a senior lecturer Dr. Dimitris Theodossopoulos has kindly shared his lecturing materials including students' assignments. Students start with a simple project (in 2018, they designed a single tier exposed timber walkway for Dirleton castle going round the walls including the viewing platform, for which they had to calculate section sizes for beams and columns according to the Eurocodes, and design the connections. Then they had to explore the difference in analysis of the beams and columns when part of a frame vs. when simply supported spans. Support of the walkway was designed next including the calculation of the most loaded column), and continue with something more complex (in 2018, they had to design a pavillion for 30 people at the same venue, solving its roof construction, envelope, decide been timber or steel frame and calculate also foundation pad to transfer the load from pavillion to the ruins, and design the connections). Apart from this, they had to submit three essays (structural analyses): 1. on a medium sized building (material variations of its main load-bearing structure and its envelope), 2. on a 5-storey steel frame residential building (to witheld the effects of typical structural loads such as dead load, imposed load, wind and fire), where a strategy for stability and stiffness had to be done, and 3. on a solid envelopes build either with large square stones or by using concrete frame (diagrams and case studies were needed).[117]

A very ineresting point of view was given to me by Dr. Paolo Beccarelli**,** an Associate Professor in Architectural Structures from the **University of Nottingham**, who not only discussed the situation at his current post, but also was able to give me a **comparison on the teaching structures to architectural students in Italy** (where he attended his architectural master courses). According to him, structural courses in Italy contain more of the actual dimensioning, apparently as in the group 1A.

To complete this topical part, let us pay attention to already mentioned **empirical design of structural members**. Architects typically do not design the structural elements, and for preliminary sizing of simple structures can rely upon standard practices sanctioned by the building codes. They can get approximate cross-sectional dimensions for common spans, heights and loads by using relatively simple rules, empirical formulas, tables or nomograms, compiled in various publications as shown below.

Following books of this type are known to students and practicing professionals in England:

[117] Case study Edinburgh, p.290

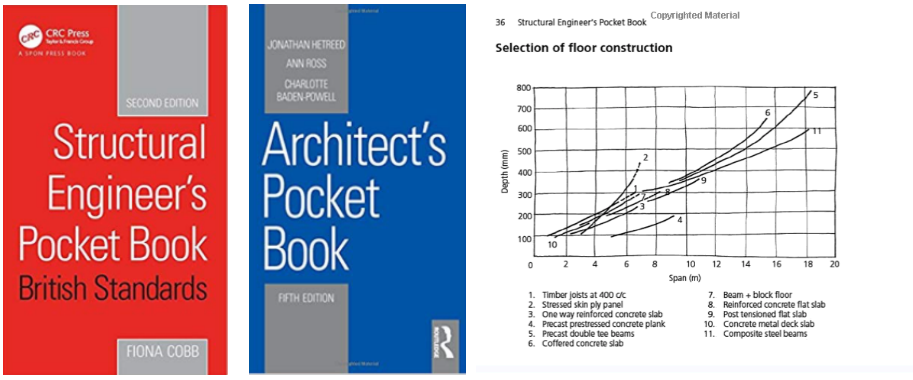


Fig.D1.1 ***Structural Engineer's Pocket Book,*** F.Cobb, 2017 (left)
The Architect's Pocket Book, A.Ross, J.Hetreed, C.Baden-Powel., 2017 (middle):
example of a nomograph from The Architect's Pocket Book (right)

However practical this approach is, I agree with Prof. Ochshorn that: "...**this method does not lead to creating simultaneously aestheticly unique and structurally effective designs** (achieved e.g. by Nervi, Candela or Calatrava to name some of the iconic "structural" architects) as similar designs need true understanding of structural behaviour". To quote Prof. Ochshorn on this matter further: "Where architects or builders wish to be adventurous with their structures, some knowledge of structural behavior and the potential of structural materials is certainly useful"[118].

Professor Ochshorn from the Cornell AAP University in the USA (a registered architect with an academic background in structural engineering from MIT) is the only one from the group of pedagogues (whose opinions I have researched on structural architectural education), who promotes empirical design attitude over the more detailed structural education for architectural students. Prof. Ochshorn authored the book ***Structural Elements for Architects and Builders***, which contains preliminary designs of beams, columns, and elements in steel, wood and reinforced concrete.

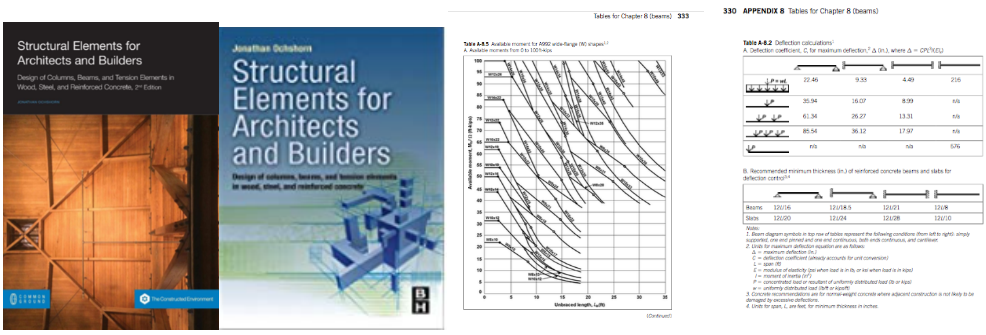


Fig. D1.2 ***Structural Elements for Architects and Builders: Design of Columns, Beams, and Tension Elements in Wood, Steel, and Reinforced Concrete***, J.Ochshorn, 2nd ed. (2015, far left), plus examples of pages.

118 OCHSHORN (2015), in the Foreword of the book

The textbook ***Structural Mechanics for Architects***[119] by Prof. Tadeusz Kolendowicz[120], which has been in use in the Czech Republik (former Czechoslovakia) for several decades is another example of literature containing i.a. **nomograms** for preliminary sizing of structural numbers. Otherwise it is very detailled and contains proper statics explaination of following topics: Loads, Structural elements and systems, Basic static principles, 2D Geometry (centroid, moment of inertia...), Friction, Supports, Trusses, Structural materials, Elasticity, Beams, Frames, Columns, Arches, Plates, Shells, Polygons and chains, Stability.

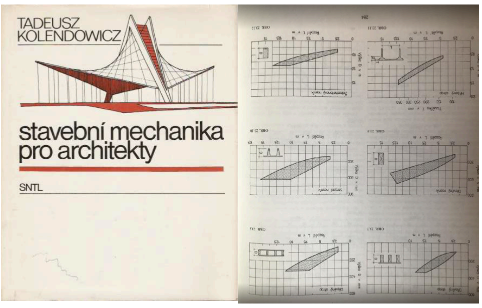


Fig. D1.3 ***Structural Mechanics for Architects***, T. Kolendowicz (1984); dust jacket and nomograph example

More recent complex publication from the field of empirical approach used in the Czech Republic is ***Design of Load-bearing Structures***[121] , which has been authored by an experienced structural engineer and associated professor at CTU in Prague, Karel Lorenz. The book consists of following chapters: Design principles, Roofs, Ceilings, Beams, Lintels, Stairs, Masonry, Columns, Tall buildings, Halls, Foundations, Construction pits and Retaining walls, and contains an easy sample calculations as well as many attachments in the form of various tables etc.

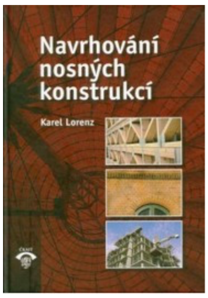


Fig. D1.4 ***Design of Load-bearing Structures***, K. Lorenz, 2015.

119 KOLENDOWICZ (1984)

120 Polish civil engineer and academic teacher, head of the Department of Structures at Wroclaw University of Technology and the Dean of the Faculty of Architecture

121 LORENZ (2015)

To **compare** all the above mentioned publications, the British handbooks are the most general ones and do not go into such detail. ***Architect's Pocket Book***[122] includes not only chapters as Structures, Building elements and Materials, but incorporates also other relevant information and disciplines (e.g. Climate maps, Metric system, Drawing conventions, Planning, Services...). ***Structural Engineer's Pocket Book***[123] is naturally more specific (with its chapters devoted to Basic and shortcut tools for structural analysis, Eurocodes, Reinforced concrete, Structural steel, Composite steel and concrete, Timber and plywood, Masonry, Geotechnics, Structural glass and building elements, Materials, Fixing and fastening besides others), but does not contain any explanations.
Ochshorn's ***Structural Elements for Architects and Builders*** is simultaneously in the form of a textbook as it contains concise introduction to structural concepts (although in a simplified form). With comparable functionality, but more detailled is Kolendowicz's ***Structural Mechanics for Architects*** (see above). Lorenz's publication ***Design of Load-bearing Structures*** is purely empirical, very detailed and well organised.

GROUP 2
GRAPHIC STATICS BASED ATTITUDE

Typical **representats** of this group: MIT Boston, USA, ETH Zurich, Switzerland, University of Cambridge, England.

Graphic statics[124] approach to structural education has been initiated by Prof. **Edward Allen** from MIT circa twenty years ago, and further developed in cooperation with his colleague Prof. **Waclaw Zalewski**. Originally historical calculation method, widespread in the second half of the 19th century (though its roots can be traced even further[125]), has been assessed as suitable for architects for displaying following characteristics: high level of clarity and visuality and minimal requirements as far as the pure mathematical training is concerned. Allen and Zalewski have authored a course textbook containing 22 chapters, each devoted to particular structural mechanics' task (e.g. to trusses, cable-stayed structures, funicular arches, shells, hanging cables....), which was further updated.[126] The successor of their work, Prof. **Ochsendorf** from MIT works on extending the scope of the method's application so it would enable also calculations of the deformations of the building structures. A detailed research on

[122] ROSS et al. (2017)
[123] COBB (2017)
[124] graphic statics principles, p.77
[125] POSPISIL (2016)
[126] ZALEWSKI, ALLEN (2009)

the new calculation methods based on graphostatics principles (in combination with probability methods) is presently taking place at ETH in Zurich under the leadership of Prof. **Block** (former doctoral student of Prof. Ochsendorf). Former MIT graduate and co-worker of Prof. Block and Prof. Ochsendorf, Dr. Michael **Rammage** has brought the graphic statics approach to architectural structural training to Cambridge University in England.

I would like to further note that although the overall general attitude to structural architectural education at these schools is based on the graphic statics, the students use "classical" structural textbooks in their studies as well - from authors such as **Schodek** (MIT), **Deplazes** (ETH), **Salvadori** or **Heyman** (Cambridge), ETH Zurich's students also work with textbook ***Faustformel*** authored by Block, Gengnagel and Peters.

As stated in Dr. Pospisil's habilitation presentation following **universities from around the world** have been already **using this approach**: Princeton University, NJ, USA, Rensellaer Polytechnic Institute, Troy, NY, USA, University Libre de Belgique, Belgium, Vrije Universiteit Brussel, Belgium, Aarhus University, Denmark, Anhalt University of Applied Sciences, Germany, EPFL Lausanne, Switzerland, University of Sao Paulo, Brasil, Independent National University of Mexico, Mexiko.

Some of the universities from the sample classified for position in group 1A (see above) have already reflected the importance of graphostatics approach by **devoting part of their architectural structural curricula to graphic statics**, e.g. CTU in Prague, Czech Republic, HCU Hamburg, Germany, TUM, Germany, RWTH Aachen, Germany, or University of Sarajevo, Bosnia and Herzegovina.

GROUP 3: ATTITUDE BASED ON THE HISTORICAL DEVELOPMENT OF STRUCTURAL MECHANICS

This attitude has been mentioned by Dr. Pospisil in his doctoral thesis[127]. The idea of teaching mechanics on the basis of its development was published as early as 1886 by **Ernst Mach**[128] and as the predecessor of this approach **Jakob Johann Weyrauch**[129] can be named. The

[127] POSPISIL (2018)

[128] MACH, E. Die Mechanik in Ihrer Entwickelung, Historisch-kritisch dargestellt
Leipzig: F.A.Brockhaus, 1883. 496 p., source: POSPISIL (2018)

[129] **Jakob Johann Weyrauch** (1845-1917): German mathematician, engineer and university rector at Technische Hoschule in Stuttgart

attitude is associated with the name of Prof. **Kurrer**[130], who created the complex structural architectural curriculum based on this approach approximately twenty years ago.

Prof. Kurrer's arrangement of structural analysis historical development into five main periods (Preparation Time (1575-1825), Discipline Creation Period (1825-1900), Consolidation Period (1900-1950), Integration Period (1950-1975) and Diffusion Period (1975 until now) is presented in a short overview in the attachment.[131]

Kurrer introduced the principles of the attitude as well as its methodology in his 1999 article: ***Plea for a historical-genetic statics theory*** [132]. In the introductory part he compares Structural Analysis (SA) to geology, which would be incomplete without paleontology expertises, and highlights the need of a broader context for SA explanation and understanding. He further writes that many students see statics as patchwork of procedures, sentences, methods and rules, and that any scientific work requires thinking in context, analyzing in context and synthesis making in context.

Kurrer is the author of the masterpiece ***The history of the theory of structures*** [133] (comprehensible historical account of theory of structures from the 16th century to the present day), initial goal of which was (according to his own words) "to add substance to the unmasking and discovery of the logical nature of SA". Over the years, it has been gradually developing by adding historical sources and collection of data from other relevant areas (didactics, theory of science, history of engineering sciences and construction engineering, historical aspects, aesthetics, biographical and bibliographical info...), until it has been made into the full picture we get now. The second edition was further significantly enlarged,

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[130] **Karl Eugen Kurrer** (born 1952) graduated from Stutgart University of Applied Sciences in 1974 (Civil Engineering degree). After working a short time as a structural timber engineer, he continued with his studies (Civil Engineering, History of technology and Physical Engineering Sciences) at TU Berlin (he completed his dissertation ***On the development of vault theory from the 19th century to today*** in 1981). Tutor at TU Berlin between 1977-1981. Finished his PhD ***On the internal kinematic and kinetic of tube vibratory mills*** at TU Berlin in 1986. 1989 - 1995: antenna systems' designer. Chair of the working group on the History of Technology of VDI (The Association of German Engineers) in Berlin since 1996. Chief editor for ***Stahlbau*** and ***Steel Construction-Design and Research*** since 2008. Published over 170 papers and several monographs: ***Geschichte der Baustatik*** (2002), ***The History of the Theory of Structures*** (2008, 2018). Received honorary doctorate from Brandenburg University of Technology Cottbus-Senftenberg in 2017.

[131] see G3 part in Appendix, pp. 362-363

[132] KURRER (1999), title in English(Plea for a historical-genetic statics theory, Theses on holistic statics for architects and civil engineers),

[133] KURRER (2008), and KURRER (2018)

incorporating b.o. FEM methods. On the creation of the book participated many professional from Germany as well as from all over the world (e.g. from Aachen, Berlin, Stuttgart, Madrid, Paris, London, Florence, Rome, Wien, Budapest, Brussels, Moscow, Vancouver, Minneapolis...).

In the chapter devoted to **didactics**, Kurrer highlights the **work of ASEE**,[134] which in his opinion brought proffesionalism into the issues of engineeering education in the USA, and later led to the **forming of the engineering pedagogy** as a part of pedagogic sciences. He writes about **Grinter's repport** from 1955[135] the ASEE reprinted in their quarterly journal of Engineering Education, where is it said, that "the next generation of engineers should devote 20% of their study time on social sciences and the humanities e.g. history", and mentiones **Swain's** book ***The young man and construction engineering*** from 1922[136], in which the author links the engineering training to the lecturing on the history of construction engineering in the USA.

Kurrer started his work whilst teaching at TU Berlin between 1977-1981, beacause he found out, similarly to Ernst Mach, that introductory lectures on history of particular SA method **could help students understand** that theory. Other goals were to **increase the motivation** of students and **evoke an enthusiasm** for learning SA. According to Kurrer, "learning from the history of SA means discovering the logic of SA from its history i.e. comprehending the principles, theorems, methods and terminology of SA as an educational process in the literal sense".

As an **example of applying Kurrer's method**, proposals for **historicised didactic approach to SE studies** by Dr. Rolf Gerhardt from 1989 are shortly described in the book. According to **Dr. Gerhardt**, "introducing the historical context into the teaching material of theory of structures in the project studies in the form of a historic-genetic teaching of structural theory **could help the methods of SE to be understood, experienced and illustrated** as a historico-logical development product, hence made more popular".

As far as the ***Plea for a historical-genetic statics theory*** article is concerned, Kurrer compiled **two sets of theses,** the first one related to **architectural and engineering practice** (Theses I, II, III), and the second one **didactic** (Theses IV, V, VI). **The first two theses** question the reason (causal aspect) and the purpose (final aspect) of a connection of the history of constructions and its theory. In the **Thesis III** he discusses conclusions for an interdisciplinary structural studies. As an introduction to the second set of theses, Kurrer

[134] **ASEE,** American Society for Engineering, founded 1893

[135] L.E.Grinter, 1955. Source: KURRER (2018)

[136] **G.F.Swain**: ***The young man and construction engineering***, 1922, source: KURRER (2018)

mentiones the historical-genetic concept developed also for scientific technical lessons at the end of 1970s by educationalists from **Bielefeld**[137]. In his opinion, the **statics theo**ry should be **shaped up holistically** and **taught interdisciplinarily**.

Thesis IV describes **traditional separation of** particular **disciplines** (statics, construction disciplines, planning disciplines...) as originated from the beginning of the 20th century, and compares that attitude with **historical-genetic concept**, which is on the contrary **based on** the **interdisciplinarity**. According to him, the process of structural learning (for historical, modern or newly-planned structures) starts with planning, continues with determining the load-bearing system, the supporting structures and the static systems. This **inductive procedure** (starts with the specific and moves towards the abstract) should demonstrate the students that various aspects should be taken into account whilst designing structures (e.g. aesthetics, room planning, insulation, radiation...), and show the **interdisciplinar nature of architectural and engineering practice**, which the lecturer should regularly refer to.

These V concentrates on the need of the **logic historical related approach** to load-bearing structures being introduced to the students. The history of structures together with history of structural theories should contribute to forming an understanding of the fact that **today's perception of structures and structural theories** is the **result** of a long-term of constructive technical and **systematic engineering development**. This understanding should help students recognize and apply current development trends in their future practice.

These VI states that **"discovery learning"** is a **mean to achieving the goals** described by thesis IV and V. The knowledge should not be mediated to students to be learned by heart, instead of it the tutor should aim to **initiate and encourage independent thinking** and mastering the problematics by via students's own thinking processes. As the most suitable forms are recommended **interdisciplinar projects** and project-like events.

According to Kurrer, the **methodology** for implementing the historical genetic concept **depends on the topic and didactic requirements**. Primarily, he distinguishes following three ways:

1. Historic logical **"Longitudinal" analysis**, analyzing the data collected on the same group on multiple occasions over the time.
2. Historic logical **"Cross-sectional" analysis**, which looks at data collected at a single point in time, rather than over a period of time.

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[137] Two experimental schools have been set up by the **University of Bielefeld** in the 1970s by educational reformer **Hartmut von Hentig**. So-called " Laboratory School" up to year ten and Oberstufen-Kolleg (an equivalent of senior high school) aimed to challenge conventional teaching concepts. The school dispensed subject teaching, the pupils worked self-reliantly and through experience.

3. **Historic logical comparison**, when two relevant stages of development from history of structures and their theories are compared with each other, noting the similarities and the differences.

Contents, goals, means and characteristics of the historical genetic statics have been organised by Kurrer into the four stages as can be seen in the attachment.[138]

The secondary grouping of schools from this research and from conferences papers

(according to the selected initiatives relevant to the SE architectural education)

For the purpose of the appraisal of attitudes to architectural structural education, I have decided to present an **additional grouping** according to the various partial approaches the schools from the sample carry out in order to enhance the structural awareness of the students worth mentioning, which are in my opinion important to reflect upon in the assessment.
In this part, **only the most notable initiatives have been selected** in order to depict the overall situation. Absence of particular university from the Case studies' part of this research in some initiatives does not necessarily mean the school does not run such activities.

INITIATIVE 1
UTILISATION OF COMPUTER SOFTWARE

The use of a computer technology is nowadays an integral part of structural design. The question arises **to what extent** and **in what form** this would be the most suitable for the process of teaching/ learning structural design.

An advantage of wide opportunities it offers should be definitely taken, but two important factors should be borne in mind: to teach the students how to **model the reality** and how to **interpret the results**[139].

Following examples of virtual platforms enabling an interactive static analysis can be named: ***Active Statics***[140] (MIT), ***Easy Statics***[141] or ***eQuilibrium***[142] (ETH), ***Donkey***[143] (CTU), ***SAFAS***

[138] see Gš part in Appendix, pp.364-367
[139] PEDRON (2006)
[140] see pp.241-243
[141] see p.71 and PEDRON (2006)

(Virginia Tech Blacksburg, USA)[144], ***NovoEd*** (Princeton University, USA)[145]. The users can almost "playfully" interact with structures, changing their parametres (form, profiles, loads) and optimalize them.

Another type of computer utilisation is represented by activities combining physical and digital modelling. In this work already described are e,g,: ***Learning Modules for Statics***[146], joint project of **Miami University and Carnegie Mellon University, USA** or activity at **University Jaume I de Castellon, Spain** described by Museros[147] . Similar activities were recounted also by many other lecturers from architectural school in various conference papers: e.g. by Prof. Chiuini from **Ball State University, Muncie, Indiana, USA** (workshops with tool ***Multiframe***)[148], by Lonnman from **Chinese University of Hong Kong** [149], by Tomovic from **Moscow Architecture School, Russia**[150], or by Hong from **Southern Polytechnic State University, Marietta, Georgia, USA**[151].

Relatively new in the field of computer utilisation in structural design education for architects are augmented reality and virtual reality applications. Notable development in this area is being reported e.g. by the team of Prof. Gengnagel from **UdK Berlin, Germany** with applications ***StructAR***, ***StructVR*** and ***StructMR***[152] gradually introduced.
Another example is the team of Dr.Turkan from **Oregon State University, USA** and their application ***iStructAR***[153] or **University of Michigan's, USA,** ***3D Lab CAVE*** as described by Emami[154].

Computer-based simulations, virtual reality and web-based interactive structural education are highly praised for reinforcing intuitive structural understanding e.g. in the papers of Emami from **University of Michigan's, USA**[155] or in a study by Causevic from **University of Sarajevo, Bosnia and Herzegovina**[156].

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[142] see pp. 72, 247, 255 for more detailed info on eQuilibrium
[143] author: Lukas Kurilla, CTU Prague
[144] SETAREH, M. et al.(2012)
[145] created by Demi Fang & team whilst at Princetown (currently works at MIT), source: EMAMI (2016)
[146] STEIF, P.S., DOLLAR, A. (2005), see p. Learning modules for Statics see p.73
[147] ROMERO, M.R., MUSEROS, P. (2002), example on pp.348-49
[148] CHIUINI, M. (2006), example on pp.338-339
[149] LONNMAN, B. (2007) see example on pp.342-343
[150] TOMOVIC, I., SOBEK, W. (2018), see example on pp.352-353
[151] HONG, P. (2011), see example on pp.356-357
[152] QUINN, G., CH., SCHNEIDER, F., GENGNAGEL, CH., GALEAZZI, A. (2018) seepp.332-335
[153] TURKAN, Y. et al.(2018), see example on pp.358-359
[154] EMAMI, N., VON BUELOW, P. (2016), see example on pp.350-351
[155] EMAMI, N., VON BUELOW, P. (2016), see example on pp.350-351
[156] CAUSEVIC, A., MILJANOVIC, S. (2014), see example on p. 354

INITIATIVE 2

INCORPORATING STRUCTURES INTO DESIGN STUDIO

The most notable papers on this topic are Prof. Chiuini's from **Ball State University, Muncie, Indiana, USA**, and Prof. Wetzel's from **Illinois Institute of Technology, Chicago, USA**.

Prof. Chiuini promotes the opinion that structural design courses should either become part of the design studio or become more "realistic" by being taught in context with a building design project[157].

Prof. Wetzel describes in a detailled analysis a six year-long experience with introducing structural design assignment into the Year 1 Studio[158] (an active experimentation with large-scale structural models).

Other academics in favour of this attitude are e.g. Emami[159] from **University of Michigan, USA**, or Soto-Rubio[160] from **University of Calgary, Canada**.

An interesting idea came also from Prof. Allen from **MIT, Boston, USA**, who suggested createing the "**second studio" (technological**), as he thought it would help to improve the efficiency of learning.

In this research, I have observed that all the universities from the sample **consider interconnecting structural design with the "real building" (student's studio work)** as **useful**, but I have noticed, that **on general English** speaking universities that have been researched usually **initiate this process at earlier stages** (e.g. earlier mentioned Bartlett School of Architecture, UCL, London, England[161]).

INITIATIVE 3

LEARNING BY DOING/ DEMONSTRATIONS ON MODELS

As refered in the literature summary, there are many studies supporting this activity as a way to improve structural understanding[162].

I would like to further distinguish between the two main approches: conducting/observing pre-set demonstrations to working with physical models (both small-scale and large-scale).

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[157] CHIUINI, M. (2006), see example on pp.338-339

[158] WETZEL, C. (2012), see example on pp.344-345

[159] EMAMI, N., VON BUELOW, P. (2016), see example on pp.350-351

[160] SOTO-RUBIO, M. (2017), example on pp.340-341

[161] e.g. Case studies/ Bartlett School of Architecture, UK; see p.268 studio

[162] e.g. PEDRON, C. (2006), JI, T., BELL, A. (2000, 2009), KHODADADI, A. (2015), EMAMI, N., VON BUELOW, P. (2016), LONNMAN, B. (2007), SOTO-RUBIO, M. (2017), TARCZEWSKI, R. et al. (2017), YAZICI, G., YAZICI, Y. (2013)

3A
CONDUCTING/ OBSERVING PRE-SET DEMONSTRATIONS

Detailed description (including rich photo-documentation) of the whole concept of structural experiments on small-scale models as put together by the team of Prof. Künzle from **ETH Zurich, Switzerland**, is available in the form of a textbook[163] [164]

As a form of introduction to structures (in the first term of architectural studies), Prof. Staffa and his team from **HCU Hamburg, Germany**, prepared and run the course ***Experimental Construction***, where students under the guidance create small-scale structures, which are then submitted to the load and observed[165].

Prof. Gerhardt from **RWTH Aachen, Germany**, was retrospectively awarded a teaching prize from the Fachschaft Architektur for the winter semester 2011/2012 for the concept of lectures and exercises (graphostatics introduction and demonstrations on models) in structural sciences for the first year's architectural students[166].

An interesting and sophisticated concept for explaining structural principles to architectural students was created at **Taubmann College of Architecture, University of Michigan, USA**, under the leadership of Prof. Buellow. ***Basic Principles of structures*** is an introductory preparatory course during which students undergo Spaghetti Tower Design challenge in order to learn and practice some basic structural pronciples. In the subsequent courses, students personnaly conduct the **pre-set demonstrations** in order to get closer to the theory. The main structural principles (adding forces, moment of a force, equilibrium, elasticity, centroid of area, shear stress, buckling in columns, deflections in cantilever beams, combined stress) are followed by structural behaviour on trusses, arches, steel beams, flitched beams and continuous beams[167].

Physical modelling as a way to improve student structural intuition is described (author's of particular papers are stated in brackets) in detail in conferences's papers mentioning the following schools: **Wroclaw University of Science and Technology, Poland** (Dr. Tarczewski et. al)[168], **Moscow Architecture School, Russia** (Tomovic and Sobek)[169], **The**

[163] KUENZLE, O. (2005)
[164] see p. 69 for examples of experiments
[165] see pp.310, 314
[166] see pp.318-319
[167] KHODADADI, A. (2015), EMAMI, N., VON BUELOW, P. (2016), see example on pp.350-351
[168] TARCZEWSKI, R. et al. (2017), see example on p.355
[169] TOMOVIC, I., SOBEK, W. (2018), see example on pp.352-353

Faculty of Architecture, Istanbul Kultur University, Turkey (Yazici, G. and Yazici, Y.)[170], **University of Calgary, Canada** (Soto-Rubio)[171].

3B
DEVELOPING OWN COMPOSITIONS/ DEMONSTRATIONS

Some schools challenge the students by open assignments requiring the creativity to come from them.

Typical example comes from **ETH Zurich, Switzerland**, where Vrontissi describes multi-level project ***Creating Equilibrium***. Students start with assembling their own equilibrium composition out of the list of household objects, which they further develop and transfer into a proper structural design[172].

Another challenge was set up at **University of Manchester, England**, by the team of Dr. Bell and Dr. Ji, where students had to create their own concept of a physical model demonstrating some of the basic structural principles. ***Seeing and Touching Structural concepts*** project led also to several booklets being printed and to creating a topical website[173]

Quite popular and frequent are at the universities also various competitions in **creating structures (usually bridges or towers) out of spaghetti**. This activity originates from the United Kingdom, has a tradition of many decades in several European, Asian and American countries, and has even developed into the world championship[174], where universities' teams compete for the most ingenious designs within the set initial parametres (such as required span, maximum or minimum height...). The bridges are evaluated in two categories: from an aesthetics point of view and by teh maximum load before collapse. The ***RECCS Pasta Bridge World Championship*** has been organised yearly by **University of Obuda, Hungary** since 2005. In 2019, 19 teams from 9 countries (Brazil, Bulgaria, Germany, Hungary, Latvia, Lithuania, Poland, Romania, Turkey) with 22 bridges took part in the event.

Various **large-scale models** are also very frequent and popular, and their pictures are spanning across most of the universities' websites. This activity challenges students' creativity, and although guided and supervised, the original concepts are usually requested to

[170] YAZICI, G., YAZICI, Y. (2013), see example on pp.346-347
[171] SOTO-RUBIO, M. (2017), see example on pp.340-341
[172] VRONTISSI et al. (2018) , see also pp.251-253
[173] JI, T., BELL, A. (2000, 2009), see also pp.298-305
[174] http://reccs.uni-obuda.hu/en/history, visited July 2020

come from students. The notable project is e.g. integrating structures into the first year studio at **Illinois Institute of Technology, Chicago, USA** as described earlier.[175] Other examples come e.g. from: **University of Cambridge** (England), **Technical University Munich** (Germany), **CTU Prague** (Czech Republic), **HCU Hamburg** (Germany), **ABK Stuttgart** (Germany), **MIT Boston**, USA...

INITIATIVE 4
INTERACTIVE STRUCTURAL DESIGN BLOG

A unique initiative in the form of an interactive structural design blog for architectural students "***structures@bath***"[176] was run between the years 2012 to 2014 by the University of Bath's lecturers Dr Evernden and Dr Darby. The aim of this blog was to improve students's structural literacy. A statics problems was set each week, followed by a forum, and later on the results were released. It also contained links to various teaching resources.

[175] WETZEL, C. (2012), see example on pp.344-345
[176] see pp.275-277

D SYNTHETIC PART

D1 CRITICAL EVALUATION

FACTUAL CRITICAL EVALUATION OF APPROACHES AND INITIATIVES IN ARCHITECTURAL SE TEACHING

Note: **Particular approaches from the pedagogical point of view** as well as the forms and types of a tuition are **examined in** detail **in the following chapter** of the study **(Discussion).**

Criteria setting

At the beginning of this chapter, I would like to present an overview of the schools's classification (primary and secondary grouping) as done in the previous part[177]:

Primary grouping

(according to the general approach to teaching SE to architects)

G1A=Group 1A: Detailed Scientific/Technical/Anglo-Saxon Attitude,

G1B=Group 1B: More practically oriented Scientific/Technical/Anglo-Saxon Attitude

G2=Group 2: Graphic Statics based Attitude

G3=Group 3: Attitude based on the Historical development of Structural Mechanics

Secondary grouping

(according to the selected features relevant to the SE architectural education)

I1=Initiative 1: Utilisation of Computer Software

I2=Initiative 2: Incorporating Structures into Design Studio

I3=Initiative 3: Learning by doing/ Demonstrations on Models

I3A=Initiative 3A: Conducting/Observing Pre-set Demonstrations

I3B=Initiative 3B: Developing own compositions/ Demonstrations

I4=Initiative 4: Interactive Structural Design blog

The following criteria have been chosen in order to produce a critical evaluation of approaches towards teaching SE to architectural students as differentiated above:

Criterion 1: **Accuracy**

Criterion 2: **Clarity**

Criterion 3: **Time** required for preparation and conduction

Criterion 4: **Feasibility**

Criterion 5: **Applicability** to the teaching process

[177] **Note:** the abbreviations (at the beginning of each line) have been assigned in order to increase clarity of the text.

Critical evaluation of "technical" attitudes (primary grouping)

The actual approach to SE architectural teaching affects an **accuracy** of the resulting practical architectural designs from structural point of view as various ways of conducting structural design predetermine the results to a certain level of exactness.

The attitude for G1A (scientific/detailed) vs. G1B (scientific/more practical), from the accuracy's point of view, can be considered as one representant as the approaches differ in this aspect only quantitatively. Simultaneously, G3 (based on implementing historic-logical connections) might be considered as of the same accuracy as G1, because it applies the same calculation methods, only uses different context (historic-logical) for introducing them to the students.

Generally speaking, the G1 (scientific) attitude is more accurate to G2 (graphic) attitude.

To evaluate attitudes G1 (G3) vs. G2, the question whether it compromises the quality of the outputs to such level that it would actually discredit them in some way for the purposes of architectural dimensioning needs to be simultaneosly assessed.

My opinion on this matter has been carefully considered on the base of assessing the information given by both actual participants and opponents of G2 method,[178] and I have come to a conclusion that **the level of accuracy of methods G1 (G3) vs. G2 does not compromise the quality of a resulting architectural structural design**.

Moreover, comparing to the possibilities of G1 (G3), **G2 further displays additional advances**: enables graphical **optimizing of the shape** of a structure as a whole, and **elimination of an order error** as it is not possible to happen whilst using the graphic method.

On the other hand, following **setbacks of graphic method with the accuracy in mind** must not be forgotten: there is a need to significantly simplify the structure and loading scheme, the actual process demands an accurate drawing, and the accuracy of results is lower for drawings in smaller scale (this can be easily overcome by using computer drawing programs).

As I do not directly connect clarity with the level of intelectual engangement, there is no need to distinguish between the groups G1A (scientific/detailed) vs. G1B (scientific/more practical) for the actual assessing of the **clarity of the methods leading to gain structural design results** (connected with particular attitudes).

(The less demanding G1B might be seen by some students as more clear due to their lower ability to grasp scientific concepts and this would lead to the appearance that G1A is less

[178] OCHSHORN (1989, 1991, 2017), GERHARDT, R., KURRER, K.E., PICHLER, G. (2003), BAXTER, S.C., JOHNSON, A., FRALICK, B.S. (2015), ALLEN, E., ZALEWSKI, W. (1997, 1998), POSPISIL (2017)

clear than G1B, eventhough it is only more demanding. One should be careful not to mix clarity with difficulty).

The overall **clarity of graphic methods** G2 is generally considered as **better compared to** the clarity of **scientific calculation methods** G1 for its high visuality and illustrativness, leading to an easy understanding. Scientific calculations require certain level of mathemathical knowledge, without which the method is reduced to being perceived just as a pure calculating aparatus without deeper sense from the students's perspective.[179] I can confirm from my own experience, that many students (especially the ones working with some model tasks) reduce their activity to rewriting formulas they do not understand, often do not know where some particular values came from, and therefore as a result make fundamental mistakes they are not aware of, stemming from misunderstanding of the formulas.

As far as the G3 (based on implementing historic-logical connections) is concerned, its main objective is to make the G1 methods more understandable by showing them in a broader context. In my opinion, I would expect this attitude being appreciated more by the students already interested in structural design, students showing difficulty in grasping the concept as such might be on the contrary overloaded by additional information to process.

When comparing G2 to G3, a "different" clarity of the methods is represented, as G2 is more clear visually, whilst G3 should boost clarity of G1 methods. Overall I would classify **G2 as more clear when targetting to represent the structural concept compared to G3**.

The **time requirements** vary significantly according to the specific situation at particular school or with particular course.

On general, **G1B** (scientific/ more practical) attitude is **less demanding on the students'** abilities (as far as the use of mathematical and other scientific apparatuses is concerned) than **G1A** approach (scientific/detailed), therefore the **preparation** of the course and an **explanation part** of **running** the course is **less time consuming for the lecturers** as well. On the other hand, **for students**, the course **G1B** is “**time balanced**“ **by focusing on the other tasks in more detail**. **G3** course is **more time demanding compared to G1**, and I would expect it to be **less time demanding compared to G2** (it would depend on the actual setting).

If the lecturer aims to prevent students copying the works of their predecessors, then slight modification of the G1 courses tasks settings is advisable. This does not nececessarily mean making it more time consuming for the pedagogue as the individual features of the “task structure“ might be easily made variable (e.g. set into a table, with columns featuring spans,

[179] e.g. PEDRON, C. (2006), POSPISIL, M. (2016), ALLEN, E., ZALEWSKI, W. (1996, 1998), GERHARDT, R., KURRER, K.E., PICHLER, G. (2003), PRAKASH, R., D.S. (1997)

heights, material specifications (type of steel) and external conditions (snow and wind loads according to the actual placing of the object), which are then gradually shifted in opposite directions, leading to the innumerable combinations being generated as a result (students are each given an inputs from the lines). Changing the overal concept of the given structure from time to time is another option of enhancing variety of the course, though slightly more time demanding on the lecturer.

For a **further comparison** of **G1** group (scientific) to **G2** group (graphic), let us remind us the above assumption that the approximate time consumption of **G1A** (scientific/detailed) and **G1B** (scientific/more practically oriented) from the student's side is being considered on about identical level (i.e. more advanced structural calculations require approximately equal effort made compared to the less strenuous calculations broaden by some explorations of practical structural issues).

From the lecturer's side, according to the own experience with G1(predominant) and G2 (to a lesser extent) types of teaching, I have found out the **preparation** of the course **G1B** as **the least time consuming**, however as far as the actual **running** of the courses is concerned, the groups **G1B and G2 compared to G1A are more demanding** on pedagogue. In the case of G1B it is because of the fact that the time he/she needs to give to each student in the form of a consultation is greater compared to time allocated to consulting pre-set exercises (that practically only need to be checked for mistakes). G2 attitude is more time consuming for the pedagogue because there is a need to train students to several skills (brought by the applying "learning by doing" attitude, e.g. learning how to model the structures, learning the basic rules for getting adding the forces and getting their resultants…) before setting the actual tasks. **G3** would be **more time demanding** for preparation and running **than G1**, and probably **less demanding** for preparation and runing compared to **G2**.

The **feasibility** is naturally to a certain extent affected by the actual allocation of time to a particular subject (as already discussed above), but what I would like to pay attention to in this paragraph are the features of each approach that in some way limit the actual attitude from practical/technical point of view. As far as the **G2** (graphic statics) group is concerned, following aspects of the method should be brought into attention: the **necessity** to significantly **simplify** the structure and the loading scheme, **limited possibilities** of calculations of **more complex structures** and the importance of **drawing accuracy** and the amount of actual work (the last aspect can be overcome by implementing some ICT drawing programs).

G1B (scientific/ more practical) **compared to G1A** (scientific/detailed) requires **more attention** from the side of a pedagogue, as the given tasks are more specific and need one to one consultations (already discussed above).

G3 (based on implementing historic-logical connections) attitude requires **more complex knowledge** base from the side of a pedagogue (extended by the historical connections) **compared to G1**, but it is **easier to run compared to G2** requiring specific "material" base.

An **applicability to a teaching process** is an indispensable aspect of each teaching approach. **G1A** method (scientific/detailed) is commonly used as it has got a long tradition and is **easy** for the lecturer **to carry out**. It is predominantly taught by frontal learning[180] and therefore represents **the most effective use of pedagogue's time**. The question is whether it epitomizes the best approach to architectural students (who might be to a certain point actually overloaded with to them meaningless scientifically derived formulas).
The **other three approaches** from this distribution of teaching attitudes (**G1B** (scientific/more practically oriented), **G2** (graphic), **G3** (based on implementing historic-logical connections)) are **little more demanding** on the lecturer for a particular reason or combination of various reasons such as lengthy **preparation**, the need of more running **time**, the need for the **teacher** to have **more complex contextual knowledge** or more demanding on the **equipment** at disposal, however they might actually be more benefitial for students.
Although the **G1B** and **G2** approaches represent to a certain extent the fact that students perform the **calculations in a lower detail**, it **does not** necessarily **compromises the quality of structural understanding** they develop. As an important feature enhancing the structural understanding, I see the actual **interconnectedness** of given tasks **with a reality**, which is represented by students' **complex studio work** (including preliminary structural design). The aspect of **interconnectedness is targetted by G3 approach**.
Overall I think that the **applicability of G1B**, **G2,** and/or **G3 attitudes to teaching**
does not substantially differ (i.e. every attitude has got its pros and cons which overall make the applicability on comparable level), and eventhough **in comparison to G1A**
they represent **more "challenge"** for the pedagogue, the other benefits classify them as appropriate to include within the teaching process.
Finally and importantly, as the most relevant aspects of the actual applicability of particular approaches or activities, (especially the "more demanding" ones from the point of time or equipment requirements as are attitudes G1B, G2 and G3) I see the fact that the tuition is to a great extent determined by **financial possibilities**[181] and **time allocation**[182] **to structural design within the curriculum** of particular faculty.

[180] p.210 (Appendix), G1.2 part (Higher education didactics)
[181] as researched by Dr. POSPISIL (2016) in his habilitation thesis, MIT's budget for one architectural student is approx. 50 thouands USD/year and ETH's cca 24 thousand CHF/year and student
[182] as observed by Dr. POSPISIL in his habilitation presentation lecture, time allocation to structural design subjects at CTU is 135 hours compared to 220 hours at ETH Zurich, Switzerland or 224 hours at MIT Boston, USA.

Critical evaluation of selected activities within the teaching process, (secondary grouping)

Initiative relevant for discussing the **accuracy** of structural design is **I1** (the **use of specialised computer software**). As already mentioned, the initiative depends on and is highly sensitive to the **precise modelling** of the inputs (structural scheme, scheme of loading the structure).[183] The disadvantage of the using computer software is seen in the **time needed to learn** how to operate particular application and "**blind trust to any outcome**" by students with limited structural perception as reported e.g. by Emami[184].

As far as the **demonstrations (I3)** are concerned, the accuracy with which the situation is modelled can be monitored here. A certain **simplification basically does not matter** as far as the demonstrated structural **principle is factually correct**. From this point of view, the **pre-set** (I3A) demonstrations are **less prone to any misconceptions** compared to student-initiated ones (I3B), however the later activities are more fruitful from the perspective of promoting creativity.

The **clarity** is an aspect, which can be assessed for all initiatives from this distribution (I1, I2, I3, I4). On general I can say that the clarity of particular selected activity **depends largely** on the actual activity's **settings and execution**, therefore can **vary to a great deal**. Nevertheless the clarity of the listed initiatives can be also **assessed from the point of their concept**. Here I would like to promote the actual "learning by doing"[185] approach over the "pure absorbing of the given facts", therefore in my opinion the **clarity for** the **I1** initiative (the use of specialised computer software) **increases with the degree of an interactivity** (e.g. platforms where students can "manipulate" with the parametres of a structure and see its response in its structural behaviour[186]).

In connection to **I2 (incorporating Structures into Design Studio)**, not the clarity of an attitude as such, but how the actual approach contemplates to clarity of the structural design problematics is going to be assessed. In my opinion, the more a certain activity is intertwined

Both MIT and ETH furthermore do not need to include in their curricula the structural design according to national standards (compared to CTU, where a tutoring in accordance with Eurocodes (European standards specifying how the structural design should be conducted withinn the European Union) is compulsory.

[183] emphasised e.g. by PEDRON (2006)

[184] EMAMI (2016) quotes Preissinger on this , CHIUINI (2006) also expresses concerns

[185] see pp.68-71, and p. 224 (DALE, KOLB)

[186] e.g. Active Statics (MIT), eQuilibrium (ETH)

with reality, the more it contributes to the relevant problematics being properly understood. Therefore I see the I2 initiative as a tool **enhancing the level of clarity of SE design**.

Initiatives **I3 (Learning by doing/ Demonstrations on Models)** can be assessed from both points of view, for the clarity of the methods themelves, and for the the way they contribute to the clarity of SE design process. The **clarity** is the **most praised feature** of structural demonstrations[187] as the structural behaviour can be immeditealy seen/observed for changing settings. I can see **I3A** initiative (pre-set) as **more demonstrative**, because of being prepared by an experienced tutors targetting to depict the required effect in its most pronounced form, nevertheless, the **I3B** initiative (students develop their own demonstrations) has its justification in being benefitial for gaining knowledge through the **"learning by doing" iterative process**. **I3A** is more challenging **for maintaining students's attention[188]** compared to **I3B**, which on the contrary **tackles students's passivity**. A critical view on structural behaviour demonstrations is voiced e.g. by Prof. Ochshorn who cites Campoli on the **risk of trivialisation** the problematics.[189]

The last mentioned **I4 (Interactive Structural Design blog)** embodies a **more challenging** method, where a clarification of a problem is delivered to the participants in later stages, after they had the chance to try to figure the problem out themselves. Although it **stimulates** the **critical thinking**, the solved problem is **not intentionally primarily clear**. The method itself is seen as a way to better understanding of structural behaviour.[190]

Criterion of a **<u>required time</u>** is not negligible as **all the listed activities** (I1, I2, I3, I4) are typically **more time consuming** compared to classical frontal learning[191].

I1 (Utilisation of Computer Software) requires some time to **learn how to operate** particular programs (and **how to model** the structure and its load). On the other hand, it is **saving time** when used **for graphical methods**, which are typical for being dependent upon the lengthy drawings. Discussing **I2 (**Incorporating Structures into Design Studio) from the point of required time is not appropriate as the benefit of an **interconnecting the architectural preliminary structural designing with the reality as much as possible is generally aimed at**, and it is up to each lecturer to **set a proper balance** between allocated time to the structural part of particular project/ gained skills.

I3 activities (demonstartions on models) are **time demanding** both for preparation and the actual running. As they are seen as of a **great learning potential[192]**, once again, it is up to the

[187] mentioned practically by all authors describing this activity

[188] see maintaining attention KHODADADI (2015)

[189] OCHSHORN 1991

[190] e.g. by RUHL (better brain function while discussing), HOLT (moreefficient learning when connections are made), SILVERMAN, DALE as referred by KHODADADI (2015), supported by VRONTISSI et al. (2017)

[191] see types of learning and their pros vs cons in G1.2 part, pp.202-236

lecturer to assess the actual benefits carefully and to **determine the right balance** reflected by the time allocated to them withing the curriculum.
I4 (Interactive Structural Design blog) is typically run as an **accompanying voluntary** activity, the main challenge of which is **motivating** the students to devote their "own time" to an extracurricular initiative. As already mentioned, the technique of a discussion and the need of a critical thinking are **benfitial** for the overall **learning process**.[193]

Feasibility and an **applicability to the teaching process** are again closely related to the **time possibilities** and to the need of an appropriate **equipment**. Both parametres **vary accordingly** in relation to the particular school's situation.

SE Teaching/ Approaches and initiatives evaluation conclusion

Sorting the schools from this sample has proved practical for the actual critical evaluation. Both **primary grouping** of schools from the sample (5 English speaking European universities, 6 German speaking European universities, MIT Boston, USA, CTU Prague, Czech Republic) according to their **overall approach** to architectural structural tuition (Detailed Scientific/Technical/Anglo-Saxon Attitude, More practically oriented Scientific/Technical/Anglo-Saxon Attitude, Graphic Statics based Attitude, Attitude based on the Historical development of Structural Mechanics) and **secondary grouping** of schools from this sample broadened by schools from analysed conferences's papers in accordance with **selected activities** supporting/enhancing the process of **teaching structures** have been introduced in order to **sort the sample** of schools and **compare** their overall attitudes and relevant initiatives within the teaching process mutually.
This conclusion represents partial findings which are going to be taken into account in later stages of the research when formulating final conclusions and recommendations.

Critical evaluation of particular approaches and inititives as reviewed in this chapter can be summed up in the following partial conclusions:

- **every attitude** has its **pros and cons** that should be taken into account when deciding on the approach and setting the structure of a course; none of the analysed attitudes can be labelled as "totally inappropriate"

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[192] e.g. by PEDRON (2006), JI, T., BELL, A. (2000, 2009), KHODADADI (2015(, EMAMI (2016), OGIELSKI et al. (2015), PLESUMS (1974), ROMERO, M.R., MUSEROS, P. (2002), SOTO-RUBIO, M. (2017), TOMOVIC, I., SOBEK, W. (2018), YAZICI (2013)...
[193] e.g. SEMRAD, PETTY (2001), Fischer (1997), MANAK, SVEC (2003), ROHLIKOV, VEJVODOVA (2012)...

- **every school** has to **determine their own targets** and **preferences**, and in relation to that allocate the **weights to** particular **criteria**; all this would result in **shaping the actual** course **schedule**
- various **"enhancing" initiatives** represent **suitable accompaniments** to the courses, but the concept of a course **should not be based solely on them**

D SYNTHETIC PART

D2 DISCUSSION

Detailed description and discussion on the methods of teaching (presentation, demonstration, discussion, cooperative learning, project learning, problem learning, investigative and research methods, simulations), on the **forms of teaching** according to the organisation (frontal learning, group learning, individualised learning, combination), on the forms of teaching according to the type of a course (lecture, seminar, exercise, study praxis, internship, excursion, expert lecture, consultation, self study), and on e-learning, **is presented in the chapter Higher education didactics.**

In this chapter of the thesis, I would like to:

- further discuss particular **approaches to teaching SE to architects** (according to the grouping in the section Critical Evaluation[194]) **from the pedagogical point of view**

- **summarize** the strengths, weaknesses, opportunities and threats **for each attitude** as well as **for the most typical forms of teaching (SWOT analysis)**.

The **main objective of** a SE architectural course **pedagogue** is identified as **to achieve students' structural competency.**

[194] Grouping of schools overviwe, see page 110

Teaching approaches / SWOT

For the **Detailed Scientific/Technical/Anglo-Saxon Attitude (G1A)** is in the early stages typical Teacher-Centered Instructional and Behaviourist approach[195]. The most common forms according to the type of course are represented predominantly by **lectures**[196] and **exercises**[197], mediated mainly **frontally**[198], however in the later stages of structural tuition, the Student-Centered Instructional and Constructivist approach prevails in the form of several **projects**[199] (based mainly on **individual** consultations), scope and complexity of which gradually progress accordingly with the time and in relation to the students' expanding knowledge. I see this distribution as logical and **justified** as there is a need to equip the students with a coherent overview of the problematics as an initial step before proceeding towards more independent individual work of their own. For the initial phase, **frontal learning is seen as appropriate** (recommended e.g. by Pecina, Zormanova[200]).

S

- there are **two types of attitude** according to the different needs in different stages of studies (getting acquainted with the problematics initially in a coherent way, and deepening the knowledge and improving critical thinking by solving problems individually in later stages)
- the tuition is **less time demanding** on tutor in the early stages[201]

W

- promoting **individualism**
- **passing the ready knowledge**, which is more difficult to remember than knowledge acquired through the active thinking process in the early stages (lower level of effectiveness compared to constructivist approaches)
- **passivity of students** in the early stages
- pedagogue **focuses on curricullum, not on the students' individual needs** (during the lectures, in the initial stage)

[195] see p. 203
[196] see pp.211-217 for detailed info
[197] see p. 219 for detailed info
[198] see p. 210 for detailed info
[199] see pp.229-230 for detailed info
[200] PECINA, ZORMANOVA, p.207
[201] simulatneously an economical advantage

O

- **to introduce innovative ways** of teaching enhancing structural understanding (e.g. working with models, using computer simulations, using graphic methods...)[202]
- **to implement constructivist methods** (e.g. problem learning, group and cooperative learning...), which would enhance forming of students' own views, and improve their ability to discuss, critically evaluate and to form conclusions[203]
- **to improve social aspects of learning in the later stages** (coworking requires to divide the work, and mediates eg. following aspects into the tuition: discussion, providing mutual control, getting an instant feedback or explanation from the peers...)
- **one way communication** (during lectures, exercises or seminars) **can be changed to mutual** communication, leading to more interactive tuition
- to target **increasing the motivation**

T

- an **overstressing the importance of innovative elements** can lead to creating a weak knowledge base (due to the not paying enough attention to theoretical explanation of principles)
- student friendly **"enjoyable" activities** (e.g. various demonstrations on models) often represent **considerable simplification** of particular topic, which might not be fully grasped by the audience as a result
- some students **cannot solve the real life tasks** (unable to apply theory into praxis) if theoretical part is overdominant to practical
- **constructivist strategies are more time consuming** for preparation and running, (also are more costly[204])
- **organisational challenges** for coworking, and for incorporating innovative methods

For the **<u>More practically oriented Scientific/Technical/Anglo-Saxon Attitude</u> (G1B)** is typical proportionally different distribution of both approaches mentioned above in the favour of the Student-Centered Instructional and Constructivist approach. As before, the **lectures** and **exercises** are typical forms of tuition, however the emphasis is put onto the **individual project**. Further present in the curriculum (to a relatively high extent) are **investigative and research methods**[205] (e.g. in the form of **case studies** of existing structures). The

[202] some of the activities already introduced to some courses, e.g. at RWTH Aachen p.318 or HCU Hamburg p.310
[203] interdisciplinary cooperation already runs at some schools or between schools, e.g. a cross/university interdisciplinary programme between UdK Berlin and TU Berlin
[204] not pedagogical aspect, added for complexity
[205] see pp. 234-235 for detailed info

seminars[206] are usually also more frequent to lectures in the More practically oriented Scientific/Technical/Anglo-Saxon Attitude.

S

- highly individualised attitude, **more adapted to the student's abilities** compared to G1A, more space to distinguish the individual speed of work
- **mutual communication** more pronounced compared to G1A
- greater opportunity to include **discussions** within the lessons (more seminars) compared to G1A
- **some of the constructivist methods already applied** (e.g. the investigative parts, discussions...)
- **passivity of students is lower** compared to G1A
- **better** accomodation when **solving a real-life problems** (more practical tasks dealt with)

W

- **lesser extent** of the actual **scope of structural theory**, **greater simplifications** of principles compared to G1A
- **more time demanding** on pedagogue
- promoting individualism if coworking is not initialised

O

- possibility of **employing innovative ways** (though in lesser extent compared to G1A as the main focus is on the project, therefore it leaves less space in curriculum for other activities)
- possibility to **incorporate** and broaden **social aspects of learning** (coworking) **in earlier stages** compared to G1A

T

- the **content-reduced knowledge base does not allow more complex structural design work**
- greater proportion of self-work compared to G1A, therefore **requiring more discipline** from the side of a student
- organisational chalenges
- **more challenging motivation/raising of interest** of students as there is less space for "enjoyable" innovative activities

[206] see pp. 217-219 for detailed info

Graphic Statics based Attitude (G2) deliveres knowledge to the students via **lectures** and **exercises** in the form of a **lab-work**. This attitude represents an innovative approach, which belongs to the category of Student-Centered Instructional and Constructivist approach. The form of an initial explanation as well as of lab instructions is **frontal**, with lab work organised in smaller **groups** enabling mutual communication between the pedagogue and students if additional explanation is needed. The following listed **features are predominantly of a technical characte**r, but their nature **predetermines an optimal pedagogical approach**.

S

- because of its visual clarity, the method **does not need lengthy explanation of rules** from the side of a pedagogue
- **quicker** optimisation when dimensioning **compared to calculation methods** (dtto)

W

- time demanding (for preparation and conduction)
- **not applicable to all** types of structural dimensioning

O

- **employing computer software** (drawing programes) for increasing speed and punctuality of the method

T

- inaccurate when diagrams not drawn meticulously

The Attitude based on the Historical development of Structural Mechanics (G3) is aimed to be run predominantly in the form of Student-Centered Instructional and Constructivist approach (approach promotes "discovery learning"), however I do not see it feasible this way to the full extent in relation to the course's content, and see its actual executing by the combination of both approaches as more likely. This attitude prefers **interdisciplinar projects** and **project-like events** to other forms of teaching.

S

- **hollistic** approach
- illustrates scientific methods
- focuses on mutual interconnections
- supports "**discovery learning**" (constructivist approach)
- should initiate and encourage independent thinking

W

- **time consuming** for preparation and running
- less time for practical design tasks

O

- **might enhance clarity** by introducing more context into structural curriculum
- **might boost motivation**

T

- **overloading** students with data

When comparing teaching approaches, the **Teacher-Centered Instructional and Behaviourist approach** (Transmissive teaching, "traditional") can be found as well as the **Student-Centered Instructional and Constructivist approach** represented in both G1 groups (the Detailed Scientific/Technical/Anglo-Saxon Attitude (G1A) and the More practically oriented Scientific/Technical/Anglo-Saxon Attitude (G1B)), though the later approach is more pronounced in G1B. G2 group (based on the Graphic methods) is based predominantly on the constructivist appoach, as is also the aim of G3 approach (based on implementing historic-logical connections).

As already described in Higher Education Didactics chapter[207], a **strong criticism of the traditional teaching** spreads widely across the nowadays pedagogical literature. **Zormanova** (2012) lists names of the most profound critics of the traditional teaching, activity of which dates back to the 19th century (e.g. Key, Dewey, Steiner, Montessori, Petersen, Parkhurst or Freinet).

Orlich et al. (1998) describes students in traditional learning process as **passive recipients**, whose abilities are mostly reduced to **memorizing facts** they do not fully understand and therefore often have **problems to apply** them in the real life. On the students's passivity agree also **Kalhous and Obst** (2012), **Pedron** (2006), **Manak and Svec** (2003) or **Rohlikova and Vejvodova** (2012), who further refer to supporting views of **Skalkova** (2004) and criticism of **Okon** (1966).

Pecina and Zormanova (2009) however **do not fully agree** with this view as they **find the traditional teaching** in its frontal form as **justified and appropriate when** there is a need to **explain difficult to understand complex topics** in order to equip the students with synoptic overview of the problematics. **Skalkova** (2004), **Rohlikova and Vejvodova** (2012) further

[207] John Dewey, see fn 289 and fn 303

warn on frequent considerable simplifications of the problematics **when modern pedagogy is used** in favour of the traditional ways.
On the other hand, the **constructivist approach** give space to teaching strategies such as problem method, discussion, project teaching, group and cooperative learning etc. that **activate the students' cognitive processes** supporting **logical thinking and creativity** (stated e.g. by **Manak, Svec** (2003)).
Pecina and Zormanova (2009) carefully examined both sides of the argument, coming to a conclusion that both **constructivism and instructivism should be appropriately combined**. This view is shared in the pedagogy community e.g. by **Tracey** (2009) who is in favour of overall **constructivist approach containing the instructional parts within**. Other advocates for combining both attitudes are e.g. **Rohlikova and Vejvodova** (2012) who **warn over the unconditional support of constructivism** stressing the importance of a scientific approach and a proper classification of certain topics.

Forms of teaching / SWOT

FORMS OF THE COURSES ACCORDING TO THE ORGANISATION

FRONTAL

S

- appropriate for creating **coherent and synoptic knowledge base**
- **economic** advantage (mass education)

W

- **not student centered**, but teacher centered
- teacher works with average speed
- teacher **cannot sort individual needs**

O

- introduce **mutual communication** (ask questions)

T

- individual need cannot be taken into account, therefore some students might be bored whilst some other might not understand

GROUP

S

- **social aspects** of learning
- motivational

W

- not an easy to keep systematisation
- the **risk of straying away** from the original task

O

- students can **discuss their tasks, divide the work, work together towards the goal, suggest different methods of tackling the problem, provide mutual control, find some mistakes, and get an instatnt feedback or some explanation** from their peers
- organisational challenge

T

- **unequal distribution** of work within the group
- **ambitious students** might not let participate others (worried about low standard of work)
- some mistakes take longer to spot and correct

INDIVIDUALISED

S

- **customised** for each student in accordance with his capabilities
- individual speed

W

- **time consuming** for pedagogue
- limited to none social learning

O

- students take **responsibility for their own progress** and results of their work

T

- some students tend not to work continuously
- students **do not acquire cooperative skills** needed for working on real life projects

The **allocation** of organisational forms of teaching within the structural curriculum is usually **proven by years of experience**, therefore straigthforward, and I **do not see the point of making any fundamental changes.** The **frontal** form is appropriate for conveying difficult to understand complex topics, and is economic, however cannot compete to **individualised** approach when proper attention towards the student is needed (projects). **What I would like to see in structural architectural curriculum more often is the group work,** which is currently used to a lesser extent, and which posesses constructivist features improving the forming of students' professional practical skills. It is based on social learning and peer cooperation. Vasutova highlights b.o. stimulant learning atmosphere and active gaining of knowledge, however possible complications as compiled by Kasikova should be born in mind (straying away, unequal distribution of work, organisationally challenging).

FORMS OF THE COURSES ACCORDING TO THEIR TYPE

As far as the forms of the teaching according to the type of a course are concerned, all four approaches from this distribution use predominantly **lectures**, **exercises** and **projects**, though the actual ratio vary as already mentioned earlier in this chapter. Other types of tuition (seminars, expert lectures, excursions, study praxis...) are used on a smaller scale compared to the main three types listed.

LECTURE[208]

S

- **quick, cheap and efficient**
- more comprehensible then selfstudy

W

- mostly **one way communication**
- **students' passivity**

O

- to **incorporate modern technologies (**links to various sources: syllabi, demonstrations, simulations...)
- simultaneous writing on a blackboard, keeping the pace
- chance to **stimulate an interest**

[208] see pp.211-217 for detailed info

- check regularly if students understand

T

- students do not come prepared

- taking notes might disturb student's perception

- do not turn into multi-media show, risk of overloading

The **lecture** is an **important part of each of the four main approaches that has been analysed**, with prevailing pros to cons. What I would like to emphasize in connection of a lecture is its concept, which should not represent monologue of a pedagogue, but **should be structured as a dialogue as much as possible**. This view is shared e.g. by **Vasutova** (2002) who further suggests to enrich the lecture with some students' activities encorporated within. This attitude simultaneously helps to tackle the issue regarding the **average attention span**, shown e.g. by **Petty** (2004**)** as around 15-20 minutes[209]. Inserted activities can simultaneously boost the attention as well as provide the feedback on students' comprehension. Strongly recommended are **short topical discussions** (recommend e.g. **Vasutova** (2002), **Fischer** (1997), **Rohlikova and Vejvodova** (2012), **Petty** (2004)). **Fischer** (1997), **Rohlikova and Vejvodova** (2012) further point out to the importance of the **questions not being answered by the pedagogue** very quickly by themselves. Desirable is also **setting a problem** at the beginning of a lecture, which the pedagogue **solves gradually in cooperation with students** (suggests **Vasutova** (2002)).

<u>EXERCISE[210]</u>

S

- practically oriented

- less students, time to address students' questions, **focus on explanation**

W

- more **time consuming** for a pedagogue (less students in a group, several groups, more overall time) compared to a lecture

[209] see Fig. G1.2.1 on p.214

[210] see pp.219-220 for detailed info

O

- **possibility to incorporate constructivist methods** (group tuition, cooperation, problem solving, simulation...) and various enhancing activities (e.g. work with models, computer simulations...)
- more chance to **tackle students' passivity**

T

- danger of **turning into a lecture**
- students **do not come prepared** which slows down the lesson

Exercise is also a **very important part** of a tuition for the reason that it provides applying of the theoretical knowlege into praxis. It is naturally **more time consuming** for the pedagogue because it runs in smaller groups, however this attitude is justified by the nature of the skills that are aimed to be taught.

PROJECT[211]

S

- connection to a real life, **complexity**
- allows **individualisation** of the task

W

- **time consuming** for pedagogue

O

- **can be done in groups**, teaches cooperation (constructivist method)
- represents **problem learning** (constructivist method)

T

- motivation of students
- **responsibility of students** to work regularly
- **insufficient knowledge** of a student to start with

Experts on a highschool didactics see the project unanimously as **benefitial**, however simultaneously stress the necessity of the project being **carefully set by the tutor**. (**Petty**

[211] see pp.229-230 for detailed info

(2004), **Skalkova** (2002), **Rohlikova and Vejvodova** (2012). The concept as such can be traced back to the turn of the 19th and the 20th century, and is connected with **John Dewey**, who did not use the term as such, though created a theoretical knowledge on which it is based.

SEMINAR

At this point, I would like to give some space to the type of tuition I **do not come across in curricula frequently**, however I consider it as **very important** for the following reasons: in my opinion, it represents **one of the most benefitial constructivist activity** for teaching students **the interpretation of the facts, argumentation, critical thinking, problem solving and cooperation.** It features following characteristics:

S

- represents **more sophisticated** form of a learning
- introduces students to the research work and its methodology
- focuses on **discussion** and **presentation**

W

- **time consuming** method (preparation, running)

O

- **teaches** students **critical thinking, argumentation, interpretation of the facts, problems solving and cooperation**

T

- students **might not be willing to participate**
- risk of monotonous re-reading of students' long elaborates
- risk of becoming a mini-lecture of its own

D3 RECOMMENDATIONS FOR FA/ CTU PRAGUE

Following part of the thesis is devoted to presenting a systematic list of recommendations for the structural architectural courses at CTU Prague that has been formulated in relation to the findings from this research:

As already mentioned, I see **achieving students's structural competency** as the main objective of a teacher. I would like the pedagogue to **focus on students' understanding of the structural principles**, as they represent the basis on which further structural knowledge could be built upon, ideally culminating by **accomplishing "structural feeling".**

Brief overview of recommendations

i overall approach:

- keep the current combination of Teacher-Centered Instructional and Behaviourist in early stages (theoretical knowledge base) and Student-Centered Instructional and Constructivist in later stages (projects)

ii conceptual approach:

- current Detailed Scientific/Technical/Anglo-Saxon Attitude is recommended
- incorporate "innovative" methods to liven up the tuition, but do not ovestimate their importance/ possibilities

iii suggested pedagogical methods

- put emphasis on projects (structural theories should be as much as possible connected with the design project)
- implement following constructivist methods to a greater extent: demonstrations, discussion, cooperative learning (interdisciplinary), problem learning, simulations (ICT utilisation)
- target increasing motivation (competitions, challenging tasks)

iv suggested pedagogical forms

- keep frontal learning **(lectures**) only for mediating synoptic and coherent base of the problematics (to minimal possible amount of time)
- implement more instructivist activities into **exercises** (problem solving, work with small-scale models, work with interactive computer programs)
- introduce more **seminars**

v professional praxis

- target including some professional experience into the curriculum

vi structural terminology & library funds

- students should get introduced to the main structural terminology in English and German
- the school can gradually expand its library/ e-library with selected structural textbooks for architects (textbooks used at major foreign universities)

Detailed description of recommendations

(including reasons for employing them, related important notes and some referrals to successful implementation of particular practices)

i overall approach

My recommendation is to **keep current combination** of Teacher-Centered Instructional and Behaviourist approach in the early stages and Student-Centered Instructional and Constructivist approach in the later stages, however I would suggest a slight modification of their current proportion in the favour of the latter one, **implementing more constructivist activities**.

Although I have noticed **pronounced interest towards "innovative" approaches** whilst undertaking this research examining situation at various universities, I **do not think** that **"innovative"** approaches **should replace traditional methods to the full extent** for the following reasons:

- there is a need for creating a coherent knowledge base (to further build on), for which according to the opinion of many didactic specialists (e.g. Pecina, Zormanova) is traditional frontal way the most appropriate
- there is a risk of the topic being fragmented and simplified when modern pedagogy is used in the favour of traditional methods (supported e.g. by Rohlikova, Vejvodova, Skalkova)
- not everything can be demonstrated in an illustrative way

Furthermore, in order to **tackle the problems of traditional methods** (students' **passivity**, **memorizing** and related inability to apply theoretical principles into praxis (as points out e.g. Pedron, Orlich, Kalhous, Obst, Manak, Svec, Rohlikova, Vejvodova, Skalkova), and in order to raise an interest in the problematics, I would propose to **focus** further **on enhancing structural tuition with selected innovative activities**.

ii conceptual approach

As far as the conceptual approach is concerned, I have detected following main attitudes to lecturing SE to architects:

G1A=Group 1A: Detailed Scientific/Technical/Anglo-Saxon Attitude,

G1B=Group 1B: More practically oriented Scientific/Technical/Anglo-Saxon Attitude

G2=Group 2: Graphic Statics based Attitude

G3=Group 3: Attitude based on the Historical development of Structural Mechanics

After submitting them to the critical evaluation, assesing following criteria: **accuracy, clarity, required time, feasibility, and applicability to teaching process,** I see **G1A attitude (Detailed scientific/Technical Anglo-Saxon, current) as the most appropriate** for running structural courses at CTU Prague for the following reasons:

- as **it is set in a close relation to practical tasks (projects)**, **further simplification would significantly reduce students' skills range,** and might even lead to disadvantaging them on the job market
- there are many "professional voices" advocating for implementing computational methods into structural engineering curriculum (e.g. Allen & Zalewski (1998), graphic and computational methods enhance each other, Chiuini (2006) as a form of preventing "black box syndrome" when computer results are used, Causevic (2014), combining numerical and graphic, Yazici & Yazici (2013))
- random professional architects I discussed the topic with did not see reducing current structural curriculum as benefitial (I think a further research in this area would be advisable as it would supply us with more data enabling statistically valid conclusion)
- although I found **graphic methods** interesting for their appealing clarity and visuality, unfortunately they display some significant disadvantages that would be difficult to overcome whilst introducing this attitude (the obligation to teach Eurocodes in the Czech Republic, lower hour dotation of the subject, inability to apply the method to some structural problems, lower budget). Current implementing of basic graphic principles withing the curricullum is in my opinion optimal, I further **suggest to offer** the students **voluntary graphic static seminar**.
- the attitude of "More practically oriented..." group puts in my opinion students in certain professional disadvantage as they finish the course with significantly lower level of structural design skills. The **research skills** students acknowledge during various **assessments of structures do not bring** in my opinion **such benefit as designing the structure itself.**
- as far as the use of the "**Attitude based on implementing historic-logical connections**" when explaining structural principles is concerned, I do not see it as a fully appropriate. Despite its **remarkable qualities in making historic-logical structural connections**, in my opinion predominantly advanced students would be interested in it, whilst **average students might get overloaded with data**. Furthermore it would most probably reduce the time allocated to individual projects (more time needed for explaining all connections). What I

would however certainly **implement** from this attitude into the learning process is its strong orientation towards **interdisciplinarity**, **coworking** and **constructivist approach**.
- I can see setting the **voluntary topical seminar** as a way to introduce historic-logical approach to students who would be interested in this matter, however when comparing the possible benefits for the students, I would find the earlier mentioned **seminar on graphic statics as more useful**.

iii suggested pedagogical methods

As the **learning-centered model** of education (constructivist) is unanimously perceived as **beneficial for activating cognitive processes** leading to **improving logical thinking** and creativity, and therefore **raises ability to solve problems** with simultaneously supporting team work (supported e.g. by Manak, Svec, Pedron), I recommend to **include following methods** into the structural architectural tuition at CTU in Prague **to a greater extent** than currently present.

The **main reasons advocating for the use** of each particular method together with some relevant notes concerning the method are **presented below in bullet-point form**.

At this place, I would also like to stress **the importance of maintaining an optimal balance between constructivist vs. instructivist approaches** as a complete replacement of instructivism is not advisable (Rohlikova, Vejvodova or Tracey).

demonstrations
- boost motivation
- involve more senses, therefore according to Dale's cone of experience leads to gaining more permanent knowledge (also supported by Confucius, Comenius, Manak, Svec, Petty)
- appropriate also within the lectures (tackles the attention span problem - according to Petty around 20 minutes)
- new experience should be related and build upon the current knowledge (according to Kolb's learning cycle)
- example from Manchester, U.K.: students were asked to come up with their own demonstrations depicting selected structural behaviour principle
- example from ETH Zurich, Switzerland: profesor Kuenzle's pre-set demonstrations on small scale models
- example from HCU Hamburg, Germany: Experimental Constructions introductory course
- example from University of Nottingham, UK: Practical structural modelling exercises

- example from University of Michigan, USA: after the initial Basic Principles of Structures Course (learning by doing, explorative character), strength and stability concepts are observed during classroom demonstrations in the Structures I course, continuing with basic principles of elastic behaviour for different materials in the Structures II course
- other examples as described in G2 part

discussion
- practices cognitive skills, activates thinking, puts emphasis on learning, not on teaching
- represents move in Bloom's taxonomy (from memorisation to application)
- not competitive but exploratory character, participant should feel free to make hypotheses, and to change views (Rohlikova, Vejvodova)
- teacher should oversee that everybody takes part (Manak, Svec)
- not many cons of the method (skillful organisation needed, necessity to deal with dominant students or unprepared students)

cooperative learning
- simulates and prepares for a real-life design process
- supports social aspects of learning
- interdisciplinary approach advocated for by Kurrer (author of historic-logical approach towards structural learning)
- example from Bath University, UK: Basil Spence Project (design competition within Design Studio 4.1) lasting approx. 8 weeks, small teams of 2-3 architectural students and 2-3 engineering students, the brief changes each year, students have to explain how the structure of their design is supposed to work and provide calculations
- example from UdK Berlin, Germany: transdicsiplinary project UdK Campus-Collisions each year (interaction between study programmes)

problem learning
- heuristic methods (enabling a person to discover or to learn something for themselves, support logical analysis) are desirable for university students as they are being prepared either for research work or for dealing with various challenges at work (Rohlikova, Vejvodova)
- problem methods can be also algorithmic (students get an exact sequence of steps, e.g. pre-set demonstartions on a small-scale models) or intuitive (more spontaneous, might not lead to a solution unless guided)
- knowledge and skills gained through problem solving are more permanent (Skalkova)
- promotes deep learning
- improves teamwork

- increases motivation
- cons needed to be taken into account (both preparation and running time consuming, varying degree of applicability and relevancy, poor performance of students in theoretical tests)

computer simulations/ interactive programs
- enhance visuo-spatial thinking and can significantly facilitate understanding of structural behaviour by allowing students create and observe alternative structural configurations (interact with structure)
- efficient when used for web-based education
- effective when combined with hands-on methods: example from Jaume I University in Castello, Spain (described by Romero, Museros), or from Ball State University, Muncie, Indiana, USA (reported by Chiuini)
Chiuini
- example from MIT Boston, USA: Active Statics
- example from ETH Zurich, Switzerland: eQUILIBRIUM
- most recent virtual reality (new possibilities): see the example from UdK Berlin (StructAR, StructVR) or from University of Michigan, USA (3D Lab CAVE)
- beware of the "black box" syndrome (students trust literally any outcome)

iv suggested pedagogical forms

As far as the pedagogical forms according to the organisation are concerned, I am in favour of combining all of them (frontal, group and individualised) for each of them display certain qualities. Benefits of the **frontal** approach have already been discussed in the part "overall approach" (appropriate for creating coherent knowledge base). **Group** arrangement supports beside others social learning, and **individualised** attitude allows customizing the speed of work together with its difficulty according to the particular student's capabilities.

When look at the pedagogical forms according to the type of a course, I recommend to run:

currently used **lectures** to start with,
- they are the most appropriate for introduction into problematics and for creating logically arranged knowledge base
- whilst preparing the lectures, student's concentration span (according to Petty around 15-20 min), and daytime performance chart by Seywert (the time slots between 8 am to 12am correspond with person's maximal performance) should be taken into account

- during lectures, mutual communication is advisable as the interactivity supports learning processes (lecturers should be aware not to answer presented questions to students too quickly)

continue with **exercises** (currently used as well),
- more practically oriented, complement lectures
- here I would suggest implementing more constructivist activities (problem solving, work with small-scale models, work with interactive structural software)

and most importantly, introduce more **seminars**
- assoc.prof. Semrad (MIAS) points to the fact that classic seminar has almost disappeared from higher education
- seminar teaches students critical thinking, argumentation, interpretation of the facts, problem solving and cooperation, introduces them to the research work and its methodology (learning how to use analysis, synthesis, comparation, analogy, generalisation, concretisation, induction, and deduction), and gives them opportunity to practice professional communication[212]
- tackles students' unwillingness to adopt an active attitude to learning[213]

- **raising interest** further might be mediated e.g. by running structural **blog** (see example from University of Bath), or setting up **competitions** (see example: pasta bridge competition)

<u>v professional praxis</u>

- represents opportunity to confront theoretical knowledge with the reality of the workplace, to test students' prerequisitions for the profesion, to connect himself with a profession or even reveal its pitfalls[214]
- some of the English universities (e.g. University of Bath) allow students to choose architectural study programmes incorporating professional praxis (which extend total length of study by 6-12 months)
- example from ABK Stuttgart, Germany: for successful completing the course, the university requires completing 3+2 internship (3 months of manual internship before starting the studies and 2 months of office work in an architectural or planning office)

[212] source: ROHLIKOVA, VEJVODOVA (2012)
[213] ROHLIKOVA, VEJVODOVA (2012) who further name, LACINA (2011) to support the argument
[214] source: ROHLIKOVA, VEJVODOVA (2012)

- example from HCU Hamburg, Germany: students have to submit the certificate of 12 weeks long construction site internship before the end of year 1, which is recommended to fulfill before starting the actual studies

vi structural terminology & library funds

Whilst conducting the research, I came regularly in touch with structural vocabulary in foreign languages. This made me realize, that compiling a list of them for the use of architectural students at CTU might prove beneficial not only for their quicker orientation in foreign professional literature, but also e.g. for looking up various information on particular topic in foreign languages. Therefore, I **recommend providing the students with the list of structural vocabulary in mother tongue and its English and German equivalents** within the structural courses.

During the examination of structural architectural literature used at selected foreign schools, I have noticed that the particular topics are not explained in the same way (authors use various illustrative sketches, photographs etc...). I think that students might find confronting their views on certain topic with slightly different attitude as interesting or even enlightening. For this reason, I would **recommend gradually expand current CTU library funds by selected foreign structural architectural literature**.

E SUMMARY AND CONCLUSION

The research on teaching Structural Engineering (SE) courses at architectural schools was initiated in 2013 by the Department of Load-Bearing Structures at the Faculty of Architecture, **Czech Technical University (CTU) in Prague** in order to **assess the importance of SE courses** as well as to get a broader insight into the problematics, the outcomes of which can be taken into account whilst **revising the current courses' scope, organisational structure and applied teaching approaches**.

There are currently two main trends in the architectural education in the Czech Republic: courses at **traditional schools** show the **trend of simplifying their curriculum** in order to comply with the lower standard of technical knowledge of incoming students, whilst **technical faculties** (often with newly established architectural study programmes, in many cases cross-listed) on the contrary **focus on technical subjects**. The faculty of Architecture at CTU in Prague belongs to the traditional group, therefore the author concentrated in the research on this category and its features. An important characteristic of this group is the fact, that as a result of the above mentioned unwilling simplifying, **some university courses** at CTU are **inherently closer to a secondary school teaching** than **to a classic university seminar**, which would develop and improve critical thinking, progressing later into an acquisition of the analytical skills (including confronting different views), and into mediating a succesful utilisation of the acquired knowledge when solving real-life professional assignments.

The candidate has set the following tasks as the **main objectives**: to **analyse the importance of SE** courses in architectural curricula, to **evaluate different pedagogical approaches to teaching SE** that have been identified on the sample of 5 English (UCL London, University of Bath, University of Cambridge, University of Edinburgh, University of Manchester) and 5 German (ABK Stuttgart, HCU Hamburg, RWTH Aachen, TU Munich, UDK Berlin) European universities (selected in accordance with the world's widely recognised rankings), expanded by MIT Boston, USA, ETH Zurich, Switzerland, and CTU Prague, Czech Republic, and **to monitor and assess "innovative activities" already applied** (including pilot seminar on Visual Statics at CTU Prague).

Applied research is used with the following methods involved: Comparison, Observation, Analysis, and Sociological Research.

The following sources have been used for conducting the candidate's research: selected **schools' websites** and **course catalogues**, **websites of related institutions** (e.g. ENHSA, SEFI, ACSA, IASS...), **universities' ranking websites** (QS World, THE World, The Complete University Guide, The Guardian League Tables, CHE Ranking, URAP Ranking, Baunetz Ranking), **educational websites**: informative (e.g. Seeing and Touching Structural Concepts (University of Manchester) and interactive (e.g. eQuilibrium (ETH), Active Statics (MIT)), **textbooks and course syllabi & presentations, pedagogy books, conferences' papers, and professional magazine's articles.**

The formulation of hypotheses took place gradually as the research progressed (described later in more detail).

SUPPORTING ANALYTICAL PART

The initial phase

At the beginning of the research, the candidate analysed **Robert Seegy's** dissertation ***Contribution to Didactics in the field of SE for Architectural Students***, describing structural courses at University of Stuttgart that have been developed with the aim to **present traditional SE to architectural students more simply and clearly, focusing** further **on employing structural creativity**. The dissertation comprises of a theoretical part and a **practical part in the form of a textbook**. **Unfortunately, only several excerpts** of the accompanying **workbook** were available, and to my disappointment **any form of evaluation/reflection** from the actual running of the courses **is absent**.

As a second step, the candidate has commissioned a **search monitoring the subject of teaching SE a**t the **National Library of Technology in Prague**. Free foreign digital libraries were searched as well as database SCIRIUS, but unfortunately, **no relevant research** was found for phrase "structural" and "construction" in combination with "teaching", "education", "learning", "research" or "methodology". My attention therefore turned towards the social networking sites for scientists and researchers such as **Research Gate** or **Google Scholar**, which proved resourceful. Authors typically describe their experience with "innovative" didactic approaches, in the most cases **including the evaluation**, and **support their conclusions** on appropriateness of implementing the tested methods by referrals to various studies by educational specialists.

The candidate has come across **two more comprehensive studies** on the teaching SE to architects whilst searching for the sources: **Claudia Pedron's** ***An Innovative Tool for Teaching Structural Analysis and Design*** and **Gbenga Martins Alalade's** ***The Pedagogy of Architectural Structures in Selected Universities in Southwest, Nigeria***.

Pedron's main focus is on the use of ICT within the structural architectural courses, introducing her **Easy Statics** platform at ETH Zurich, Switzerland (stressing the importance of proper modelling the real-life structures together with the correct interpretation of given results), nevertheless considerable proportion of her work is devoted also to **discussing the teaching attitudes** (highlighting and arguing for the necessity of incorporating more constructivist activities).

Alalade investigated the situation at four universities in Southwest, Nigeria, handling random sampling techniques on the **sample of 288 students**, whom he submitted to a **structured questionnaire** and **guided interview**, and later processed the data in the **content analysis**. He was evaluating the curriculum, assessing the use of ICT, and examining the teaching approaches in relation to students' personality characteristics and their learning styles by the means of **observation** and **comparison**. His main conclusions put an **emphasis on the design studio-oriented approach, promoting visual-spatial thinking**, and recommending **wider adoption of digital technologies**.

LITERATURE REVIEW has been conducted for around fifty scholarly articles as well as for a few longer works (dissertations) on the topic the candidate has encountered and analysed during conducting this study.

The articles basically deal with the **four main questions**:

1. The importance of structural courses within the architectural curricula (resp. the importance of structural literacy) on which (with the exception of Prof.Ochshorn's interesting view) consensus was reached as being significant for architects.

2. The implementation and extent of a scientific approach within the courses (mathematical formulas, scientific character of explanation...) was not completely excluded, however, the situation seems to be more in the favour of simplification.

3. The broad topic discussion on the actual form of structural courses as such has turned out as repeated demand for linking the theory with praxis i.e. mainly by joining structures with studio as well as incorporating active exploratory activities within (work with small-scale structural models).

4. Use of the ICTs has been unanimously appraised (though with certain reservations); the main focus is on the possibilities of virtual reality for education.

HIGHER EDUCATION DIDACTICS part represents one of the **supporting analyses of this research**.

This section has been approached by researching Czech and English sources on the **problematics of the teaching in general** (e.g. Petty: *Teaching Today*, Zormanova: *Teaching Methods in Pedagogy*), **specific pedagogy works devoted to higher education problematics** (mainly Czech literature sources (e.g. Rohlikova & Vejvodova: *Teaching*

Methods at the University, Kasikova: *Cooperative Learning, Cooperative School*), international **dissertations** (Pedron, Alalade) and **conferences' papers** specializing on **higher education architectural structural pedagogy** (Allen & Zalewski, Chiuini, Emami, Gerhardt, Ochshorn, Vrontissi, Wetzel...).

The **two main approaches** to teaching have been acknowledged: **transmissive**, or **"traditional"**, following one of the three teaching concepts: dogmatic (medieval teaching through passing knowledge), verbally-presented (with the focus on visual clarity (Comenius)), verbally-reproductive (based on memorisation without prior understanding (Johann Friedrich Herbart), and **constructivist**, or **"innovative"**, linking the school learning with with an **applying the knowledge in the real-life situations** (problem learning), introduced by John Dewey (philosopher, psychologist and educational reformer of the turn of the 19th and 20th centuries) .

The basic classification of the **forms of the teaching** can be done **according to the organisation** (frontal, group, individualised, combined), or **according to the type of the course** (main methods (lecture, seminar, project, exercise), complementary methods (praxis, excursion, self study, consultation...).

As far as the **methods of teaching** are concerned, they can be primarily sorted as follows: presentation and demonstration, discussion, cooperation (partner or group), project solving, problem solving, research methods, simulation, situation and inscenation methods.

To the **general characteristics** and variety of opinions of several educational specialists on the topic relevant to particular approaches, forms and methods of teaching is devoted the **Higher Education Didactics** chapter, whilst detailed **evaluating of the appropriateness of particular approaches, forms and methods** of teaching for the teaching at the Faculty of Architecture at CTU Prague (with the focus on their pros and cons) is **discussed in the synthetic part of this research** (chapter Discussion).

To briefly sum up the present higher education didactics problematics as seen by the Czech leading specialists (e.g. Kasikova, Manak, Rohlikova, Skalkova, Svec, Vejvodova, Zormanova), there is a trend to **move away from the "traditional" transmissive (instruction based) methods**, and to **incline towards the "modern" innovation (constructivism based) methods** and towards the more complex forms of teaching. At the same time, the experts also **highlight the problems** related to the **uncompromising rejection of the traditional pedagogy in the favour of modern trends** such as the low level of effectiveness of constructivist methods for certain cases, or considerable simplifications of the learning materials.

THE CASE STUDIES

For the purpose of the research, I have had a closer look at how SE is taught to future architects at the following **European universities lecturing in English language**: UCL London, University of Bath, University of Cambridge, University of Edinburgh, University of Manchester, **European universities lecturing in German language**: ABK Stuttgart, ETH Zurich, HCU Hamburg, RWTH Aachen, TU Munich, UDK Berlin, and to **leader in graphostatic approach**: MIT, Boston, Cambridge, USA.[215]

Apart from the above mentioned detailed case studies part, I have also compiled an overview of interesting pedagogical activities (related to SE architectural teaching) from all over the world on the base of analyzing various conferences' papers.[216]

After thoroughly analysing the study plans of eleven selected European English and German speaking universities and having look at the teaching approach of MIT Boston, Cambridge, USA, as well as going through approximately fifty conference papers discussing various activities applied to structural teaching at architectural schools, I came to a conclusion that although quite a substantial amount of time has passed since the quote of Richard Bender, saying that:
“The **classical sequence of presenting statics, strength of materials, analysis and 'design'** may represent a logical progression of information. However, divorced as it usually is from involvement with the total process of design, this sequence has resulted in architectural graduates who have no understanding of the basic principles involved, cannot apply them, nor retain for a significant period after graduation the basic core of material encountered.”[217],
the setting of architectural structural curricula is moreless the same ". This fact to a certain point proves **the importance of logical arrangement of the knowledge that needs to be passed to students.**
What has however greatly improved since is a **noticeable shift in the original lack of involvement in the process of design**, which was achieved by a more close relation between the statics courses and project, by **implementing enhancing activities** supporting better understanding (experiments, site visits, workshops), by using specialised software (taking

[215] G1.3 part, pp. 237-335
[216] G2 part, pp. 337=359
[217] as quoted by CHIUINI (2006), originally from BLACK, DUFF (2004)

over complicated calculations, virtual modeling), and mostly by **applying modern teaching methods** (hands-on-learning, problem learning).

ANALYTICAL- SYNTHETIC PART

Qualitative (ways of teaching SE) **and quantitative** (% content of SE subjects) **analyses of architectural structural curricula at selected schools** represent an **analytical-synthetic** part of candidates's research, aim of which is to contribute to the overall assessment of the **importance of SE subjects in the architectural curricula**.

1.

As a first step, the introductory quantitative study:

Share of Structural Engineering in Curricula at Selected European Universities[218] with the objective to get an initial insight into the problematics has been conducted.

The **CTU Prague's** (CTU) **architectural programmes have been compared to** the programmes of the **two leading English** speaking universities (University of Bath (UB), United Kingdom, London Imperial College (ICL), United Kingdom), and the **two leading German** speaking universities (Technical University of Munich (TUM), Germany, Technical University of Zurich (ETH), Switzerland).

The actual bachelor and master study programmes compared: **Architectural Design** (AD), **Architectural Engineering** (AE) and **Civil Engineering** (CE) (Building Structures specialisation only).

The courses taken into account: **Structural Mechanics, Statics, Concrete Structures, Steel Structures, Wooden Structures** and **Foundations**.

In accordance with the results, the **first two hypotheses** have been formulated:

H1 The percentage share of SE subjects in bachelor architectural curricula of German universities is higher compared to other European universities.

H2 The share of Structural Engineering subjects at Faculty of Architecture at CTU in Prague is underrepresented in context to other selected European English and German universities.

[218] POSPISIL, VAVRUSKOVA (2013)

2.

Subsequently, the **quantitative** analysis was elaborated in greater detail in the **follow up study**:

Share of Structural Engineering in Curricula of CTU vs. Selected European Faculties of Architecture[219], an objective of which was to get % volume of SE subjects in curricula on broader sample (27 selected German (15) and English (12) speaking universities) in order to validate/refute H1 and H2 hypotheses. The study was conducted for Architectural Design (AD) and Architectural Engineering (AE) programmes. The **selection** of European English and German speaking universities has been done predominantly on the basis of the schools occupying prime positions in world independent **rankings**.

Conclusions, evaluating previous hypotheses, forming new hypotheses

- **The share of SE in architectural curricula** at selected European universities varies considerably **(5-42% in bachelor courses** and **0-45% in master courses)**.
- **German speaking** and the **top rated UK** universities **tend to have a higher than average share of SE** in their architectural curricula. (**SE in bachelor: cca 35% for leading British and AE combined courses, 10-15% for most English-speaking, 15-25% for German speaking, SE in master: up to 5%, when further specialisation** in SE, it **boosts** share of SE subjects **to 10-45%)**.
- **An 8.33% share of SE in bachelor studies at CTU seems to be underrepresented in context** of the above-mentioned European universities, where such share most typically ranges between 10-25%.

In accordance with the results above, the **H1 hypothesis can be classified** as **partly verified**, and **H2 hypothesis** as **verified.** New hypotheses H3 and H4 have been formulated:

H3 Volume of Structural Engineering subjects in architectural curricula is on comparable levels for selected major Czech (and potentially Slovak – because of joint history as Czechoslovakia in the years 1918-1992) technical universities.

H4 Having allocated more time to Structural Engineering in their bachelor architectural curricula, students at German and the top rated British universities are taught a wider range of SE topics than students at other European faculties of architecture from the selection.

[219] POSPISIL, VAVRUSKOVA (2014)

3.

Simultaneously, the **introductory qualitative study** (on the teaching methods):
New Ways of Teaching Statics and Applied Structural Mechanics to Architects[220] was published, giving an initial insight into the problematics of different ways of teaching SE to architectural students.

In collaboration with two other authors, who provided an introductory description of the general situation in architectural structural education in the Czech Republic and an overview of the schedule of the structural courses at CTU Prague, the candidate referred on the main differentiating of approaches to teaching structures to architects as **traditional vs. innovative**, and briefly introduced the **three most typical innovative forms** (graphic methods, ICT implementation, work with small-scale models).

As a result, a new hypothesis has been formulated:

H5 Innovative teaching methods are more appropriate for teaching SE subjects to architectural students than traditional frontal methods.

4.

In order to examine hypothesis H3, the candidate further proceeded to undertake the following **supplementary quantitative study**:
Structural Engineering in Architectural Studies *(New ways of teaching Structural Engineering and its share in curricula at selected Czech and Slovak Technical Universities)*[221].

The following Czech (Brno University of Technology (BUT), Technical University of Ostrava (TUO), Technical University of Liberec (TUL)) and Slovak (Slovak University of Technology (STU)) universities were chosen for the analysis comparing their compare % volume of SE subjects in curricula to one of the Czech Technical University in Prague (CTU).

It was shown that the **share of SE subjects** ranges between **5-8% in bachelor** architectural curricula and **up to 5% in master** architectural curricula at the above selected Czech and Slovak technical universities.

[220] POSPISIL, VAVRUSKOVA, VERTATOVA,(2014)
[221] POSPISIL, VAVRUSKOVA (2015/1)

The results verified hypothesis H3, which expected the % share of SE subjects in architectural curricula at Czech and Slovak universities being on similar level.

5.

In the next step, further attention was devoted to gaining a deeper insight into the teaching methods of the architectural structural tuition by further exploring the main teaching approaches as well as particular innovative methods. The findings of that phase of candidate's research are described in the **follow-up qualitative study** on the teaching methods:
Teaching Structural Engineering to Architects *(Traditional vs. innovative methods of teaching (at CTU Prague and at selected European Universities))*[222]

The final conclusion on H5 has not been made at that point, but an agreement has been made on Pedron's statement, that students of architecture are accustomed to learn in a visual, creative way, therefore **student-centered instruction and a constructivism approach** seems to be **more beneficial** for them.

The candidate then continued working on the qualitative part of the research, resulting in the two following conference papers:

6.

Structural Engineering in Architectural Studies at CTU Prague
(New ways of teaching Structural Engineering at CTU Prague and its share in curricula compared to selected European faculties of architecture)[223] represents the **focused qualitative study introducing the Visual Statics course** (Structural Mechanics seminar).

As a part of the candidate's research, a newly introduced seminar at the Faculty of Architecture, CTU Prague, was assessed.
It has been observed, that students entering architectural studies at CTU Prague display a relatively low level of knowledge in technical subjects, subsequently leading to the need of modifying the courses on structural mechanics. The Visual Statics course has been developed as **an intermediate link** between the **introductory theoretical structural mechanics** courses and **subsequent load-bearing structures** courses, the aim of which is to deepen and strengthen the initial structural knowledge in an engaging way. The Visual Statics course is

[222] POSPISIL, VAVRUSKOVA (2015/2)
[223] POSPISIL, VAVRUSKOVA (2016/2)

based on Graphic Statics and currently consists of six seminars analysing principles of static behavior for five types of isostatic plane structures. At the beginning of each seminar, there is a short introduction on elementary theory describing static behavior of related structures, closely followed by a "hands-on" experiment. Appropriate virtual computer-aided model is created with a loading simulation to verify the experiment and a calculation is finally completed by structural assessment using graphic statics.
The concept has been run-tested and fine-tuned, and is going to be offered as a voluntary supplement to the regular part of a curricula. The participants' feedback has been positive.

H5 evaluation: I cannot agree to a full extent.
In my opinion, **hands-on experiments are of a great didactic value and indisputably apt especially for architectural students** (who are predisposed to learn in a visual – creative way), however I would consider conducting them without any "technical" base knowledge already gained (by frontal methods of teaching) as more complex to carry out, therefore **I would not choose to employ them solemnly, but opt for using them only as a supplement** to the current courses.

7.
The following **specific qualitative analysis**:
Aims and Content of Structural Engineering Courses in Architectural Studies at Selected European Universities *(Comparative study for CTU in Prague, Czech Republic, the University of Bath, United Kingdom and the University of Stuttgart, Germany)*[224]

has been performed on both AE and AD programmes at three selected universities in order to **further investigate the reasons behind partly verified H1** (more SE subjects in German and English universities' curricula), and to **verify/refute H4** (? wider range of topics at universities with more time given to SE). I wanted to explore whether these universities cover more areas of SE? / cover comparable extent of SE but in a wider context? / cover a comparable range of topics, but assign more time to practice?...

Within the research, I have looked in detail at the schools': Introductory SE course, Follow-up SE courses, Introduction into the Building Constructions, Detailed Structural Design & Design Studio, Other related courses / activities, Further specialisation / Specialised areas of interest.

[224] POSPISIL, VAVRUSKOVA (2016/1)

I have found out that the **aims, content and targeted skills** (when considering similar types of courses) **are almost identical.**
Students should **get familiar with different types of structural materials**, with **basic statics principles**, and with the **concepts of structural design.** They should be able to **apply the knowledge in the context of a design problem**.
What **differs slightly is the position of courses with the similar content in the curricula's timetable,** however within the means of logical sequencing (detailed overview is presented in the form of a table).[225]

<u>Hypothesis H4 (a wider range of topics at schools with more time devoted to SE) was therefore refuted.</u>
When I put it into the context, I came to the conclusion, that students at CTU Prague are at certain disadvantage, as **English and German students seem to have more thorough and detailed training** in order to adapt the skills needed for creating an effective design of the structure (when take in account following facts: SE in curricula: CTU 8.33 %, av. English 10-15 %, av. German 15-25 %, aims, content and targeted skills almost identical).
Furthermore it seems that **English and German students benefit** from incorporating **innovative methods** of teaching into the learning process (e.g. hands-on experiments), **guided cooperation seminars with civil engineering students** and compulsory **work placement** as a part of their bachelor courses.

8.
Finally, an <u>**additional supplementary qualitative study**</u>:
Teaching Structural Engineering to Architects
(Structural Mechanics vs. Structural Design mix within the curricula)[226]
has been conducted on the sample of 27 selected European German and English speaking universities from the previous research (number 2).

The candidate was analysing the ratio between Structural Mechanics (SM) (theoretical introduction into basic laws and principles of mechanics) and Structural Design (SD) (practical, detailed design of particular structural members) subjects within the architectural curricula for Architectural Design (AD) and Architectural Engineering (AE) programmes:

[225] attached in the thesis pocket
[226] POSPISIL, VAVRUSKOVA (2017)

The results showed that on average, **structural courses are split between SM and SD** for both AE and AD programmes **approximately evenly**, with the situation more pronounced for AE courses. It was further found out that compared to the previous research, **more universities** from the sample **started to offer combined AE courses** (5/27 in 2014 compared to 9/27 in 2017).

SYNTHETIC PART

GROUPING OF SCHOOLS FROM THE SAMPLE

As a preparation for subsequent critical evaluation of teaching approaches and initiatives relevant to teaching SE to architects, the **schools from the analysed sample** (the main case studies and the case studies from the conference papers) **have been** further **sorted** on the basis of displaying similar features as displayed below:

Primary grouping

(according to the general/ conceptual approach to teaching SE to architects)

G1A=Group 1A: Detailed Scientific/Technical/Anglo-Saxon Attitude,
G1B=Group 1B: More practically oriented Scientific/Technical/Anglo-Saxon Attitude
G2=Group 2: Graphic Statics based Attitude
G3=Group 3: Attitude based on the Historical development of Structural Mechanics

Secondary grouping

(according to the selected features relevant to the SE architectural education)

I1=Initiative 1: Utilisation of Computer Software
I2=Initiative 2: Incorporating Structures into Design Studio
I3=Initiative 3: Learning by doing/ Demonstrations on Models
I3A=Initiative 3A: Conducting/Observing Pre-set Demonstrations
I3B=Initiative 3B: Developing own compositions/ Demonstrations
I4=Initiative 4: Interactive Structural Design blog

FACTUAL CRITICAL EVALUATION
OF APPROACHES AND INITIATIVES IN SE TEACHING

The following criteria have been set for the actual evaluation: **Accuracy**, **Clarity**, **Time** required for preparation and conduction, **Feasibility**, **Applicability** to the teaching process.

Approaches evaluation (factual)

Generally speaking, the G1 (scientific) and G3 (historic-logical) attitudes are more accurate to G2 (graphic) attitude, however **the level of accuracy of methods G1 (G3) vs. G2 does not compromise the quality of a resulting architectural structural design**. **G2** furthermore **displays some advances** (possibility of the shape optimisation, or order error elimination), but on the other hand **cannot be used for all types of structures**.

The overall **clarity of graphic methods** G2 is generally considered as **better compared to** the clarity of **scientific calculation methods** G1, but in comparison to G3, G2 prevails with its visual illustrativness. The actual clarity of G3 compared to G1 is discutable, as in my opinion G3 would mediate better understanding to students already interested in structures, whilst other students might be actually overloaded with data.

The **time requirements** vary significantly according to the specific situation at a particular school or with a particular course, but G2 and G3 are more demanding on the pedagogue both for preparation and running compared to G1. G1B also demands more of the pedagogue's time due to the more pronounced individualised part of tuition compared to G1A. G3 is in my opinion less time demanding compared to G2.

The **feasibility** brings the question of necessary equipment (more needed for G2) as well as the actual extent of the time available (e.g. lecturer would probably not include interactive activities into lessons if there is barely enough time for frontal explanation of problematics). G3 requires a more complex knowledge base of the pedagogue.

An **applicability to the teaching process** is a very important parameter. G1A and is **easy** for the lecturer **to carry out** and represents **the most effective use of the pedagogue's time**. The appropriateness of sole use of this attitude is questionable for reasons already mentioned (too scientific, not interactive enough, difficult to understand without practical application...), however the two other attitudes (G2 and G3) are indisputably more demanding as far as the preparation, running time and funding is concerned, their other benefits (supports thinking processes, and their interactive nature leads to better understanding) classify them as appropriate to include within the teaching process.

Initiatives evaluation

The initiative relevant for discussing the **accuracy** of structural design is **I1** (the **use of specialised computer software**) as it is highly sensitive to the **precise modelling** of the inputs. As far as the **demonstrations (I3)** are concerned, a certain **simplification basically does not matter** as far as the demonstrated structural **principle is factually correct**.

The **clarity** is an aspect, which can be assessed for all initiatives (I1, I2, I3, I4). Generally, it **depends largely** on the actual activity's **settings and execution**. As far as the conceptual clarity is concerned, I would like to promote the actual "learning by doing"[227] approach over the "pure absorbing of the given facts" (in my opinion the **clarity increases with the degree of an interactivity)**.

Criterion of a **required time** is not negligible as **all the listed activities** (I1, I2, I3, I4) are typically **more time consuming** compared to classical frontal learning.

The feasibility and an **applicability to the teaching process** are again closely related to the **time possibilities** and to the need of appropriate **equipment**.

To sum up my findings from this part**,** I find as important that **every school determines their own targets** and **preferences**, and in relation to that allocates the **weights to** particular **criteria**. This would result in **shaping the actual** course **schedule**. None of the analysed attitudes can be labelled as "totally inappropriate", but **every attitude** has its **pros and cons** that should be taken into account when deciding on the approach and setting the structure of a course. As already mentioned, I would find various **"enhancing" initiatives** as **suitable accompaniments** to the courses, but the concept of a course **should not be based solely on them**.

After submitting the above conceptual approaches to the critical evaluation, I have found the G1A attitude (**Detailed scientific/Technical Anglo-Saxon**, current) **as the most appropriate for** running **structural courses at CTU Prague** for the following reasons:

- as it is set in a close relation to practical tasks (projects), **further simplification** would significantly **reduce students' skills** range (might even disadvantage them on the job market),
- many "professional voices" call for implementing **computational methods** into the structural curriculum e.g. Chiuini (2006) as a form of preventing "black box syndrome" when computer results are used, Causevic (2014), combining numerical and graphic, Yazici & Yazici (2013), even graphostatics pioneers Allen & Zalewski (1998) say that graphic and computational methods enhance each other).

[227] pp. 68-71

- although I regard the **graphic methods** interesting for their appealing clarity and visuality, unfortunately they display some significant disadvantages (the obligation to teach Eurocodes in the Czech Republic, lower hour dotation of the subject, inability to apply the method to some structural problems, lower budget).
- the attitude of the "**More practically** oriented..." group puts in my opinion students in certain professional disadvantage as they finish the course with significantly lower level of structural design skill, furthermore the research skills students acknowledge during various assessments of structures do not bring in my opinion such benefit as designing the structure itself.
- I do not see the "**Attitude based on the historic-logical connections**" when explaining structural principles as fully appropriate. Despite its **remarkable qualities**, in my opinion predominantly advanced students would be interested in it, whilst **average students might get overloaded with data**. It would also reduce the time allocated to individual projects. What I would **implement** from this attitude into the learning process is its strong orientation towards **interdisciplinarity**, **coworking** and **constructivist approach**.

<u>DISCUSSION/ TEACHING APPROACHES & FORMS OF TEACHING (FROM THE PEDAGOGICAL VIEW)</u>

In this part, the candidate submitted the found approaches to teaching SE to architects (according to the grouping in the section Critical Evaluation) to the SWOT analysis (from the pedagogical point of view), followed by a discussion on the appropriateness of a particular approach and methods for the structural tuition at the Faculty of Architecture at CTU Prague.

The <u>two main approaches</u> to teaching: **Teacher-Centered Instructional and Behaviourist approach** (Transmissive teaching, "traditional") as well as the **Student-Centered Instructional and Constructivist approach** are present in both G1 groups. (the Detailed Scientific/Technical/Anglo-Saxon Attitude (G1A) and the More practically oriented Scientific/Technical/Anglo-Saxon Attitude (G1B)), though the later approach is more pronounced in G1B. The G2 group (based on the Graphic methods) is based predominantly on the constructivist approach, as is also the aim of the G3 approach (based on implementing historic-logical connections).

As already mentioned, the criticism of "traditional" teaching is currently being brought up regularly (with the passivity of students being the most criticised aspect (Orlich (1998), Pedron (2006), Kalhous and Obst (2012), Manak and Svec (2003), Skalkova (2004), Rohlikova and Vejvodova (2012)), and benefits of constructivist methods being highlighted (**activating students' cognitive processes** supporting **logical thinking and creativity**, therefore also an ability to solve a real-life problems), but there are also the voices **finding the traditional teaching** in its frontal form as **justified and appropriate when** there is a need to **explain difficult to understand complex topics** in order to equip the students with synoptic overview of the problematics (Pecina and Zormanova (2009). To make their position stronger, Skalkova (2004), Rohlikova and Vejvodova (2012) further **warn on frequent considerable simplifications** of the problematics **when modern pedagogy is used** in favour of the traditional ways. Many supporters of the combined approach have been found, e.g. Pecina and Zormanova (2009) saying that **constructivism and instructivism should be appropriately combined**, Tracey (2009) preferring the overall **constructivist approach including the instructional parts within**, or Rohlikova and Vejvodova (2012) who **warn over the unconditional support of constructivism**.

The constructivism can be incorporated into structural architectural tuition by implementing the folowing methods: **demonstrations** (involves more senses, therefore according to Dale's cone of experience leads to gaining more permanent knowledge (also supported by Confucius, Comenius, Manak, Svec, Petty)), **discussion** (practices cognitive skills, activates thinking, puts emphasis on learning, not on teaching, represents move in Bloom's taxonomy (from memorisation to application)), cooperative learning (simulates and prepares for a real-life design process), **problem learning** (enabling a person to discover or to learn something for themselves supports logical analysis, knowledge and skills gained through problem solving are more permanent), **computer simulations/ interactive programmes** (enhance visuo-spatial thinking and can significantly facilitate the understanding of structural behaviour).

As far as the forms of the teaching according to the type of a course are concerned, all four approaches from this distribution use predominantly **lectures**, **exercises** and **projects**, though the actual ratio varies. Other types of tuition (seminars, expert lectures, excursions, study praxis...) are used on a smaller scale compared to the main three types listed. I see the **lecture** as an **important part of each of the four main approaches I have analysed**, with prevailing pros to cons (see above). The exercise is in my opinion also an **essential part** of a tuition; although being more time consuming for pedagogue, its importance lies in providing and applying of the theoretical knowledge into praxis, an aspect which culminates in **projects**, which should be present in architectural tuition to the highest possible extent (recommended unanimously by the teaching experts, and also assessed as the most beneficial activity when discussed the problematics with the students I had the pleasure to teach for several years at CTU Prague).

What I would like to see more in the architectural structural tuition is the **seminar** teaching the students critical thinking, argumentation, interpretation of the facts, problem solving and cooperation, introducing them to the research work and its methodology (learning how to use analysis, synthesis, comparison, analogy, generalisation, concretisation, induction, and deduction), and giving them an opportunity to practice professional communication.

RECOMMENDATIONS

FOR THE FACULTY OF ARCHITECTURE/ CTU PRAGUE

i overall approach:

- keep the current **combination of Teacher-Centered Instructional and Behaviourist in early stages** (theoretical knowledge base) **and Student-Centered Instructional and Constructivist in later stages** (projects)

ii conceptual approach:

- current **Detailed Scientific/Technical/Anglo-Saxon** Attitude is recommended
- incorporate "**innovative**" methods to liven up the tuition, but **do not overestimate** their importance/ possibilities

iii suggested pedagogical methods

- put **emphasis on projects** (structural theories should be as much as possible connected with the design project)
- implement the following **constructivist** methods to a greater extent: demonstrations, discussion, cooperative learning (interdisciplinary), problem learning, simulations (ICT utilisation)
- target increasing **motivation** (competitions, challenging tasks)

iv suggested pedagogical forms

- keep frontal learning **(lectures**) only for mediating synoptic and coherent base of the problematics (to minimal possible amount of time)
- implement more instructivist activities into **exercises** (problem solving, work with small-scale models, work with interactive computer programs)
- introduce more **seminars**

v professional praxis

- target including some **professional experience** into the curriculum

vi structural terminology & library funds

- students should get introduced to the main **structural terminology in English and German**
- the school can gradually expand its library/ e-library with selected **structural textbooks** for architects (textbooks used at major foreign universities)

Final conclusion

Cambridge Architecture UG Handbook introduces its technical courses with the following statement: "...**there is no aspect of the technical side of architecture that is too complicated to be introduced to students**", and that: "...an awareness of the complexity and richness of the subjects involved best represents the richness and excitement to be found in architectural practice. Therefore it is not assumed that there are any areas that cannot be discussed but are "best left until later" or that "you do not need to know yet" or that "are better learnt in practice"." **The emphasis is placed on learning methods and approaches to technical issues; what the technical issues are; and how and where to find more help or information**."[228]

The quote above supports my opinion that **learning methods are the key components** influencing the level of success of the learning process. As stated by Comenius, one of the objectives of didactics is to find the way how to "teach less whilst students learn more".[229] After getting acquainted with behaviourist psychological theories of constructivism applied to pedagogy, and analysing teaching methods and curricula contents of the selected leading European German and English speaking universities, the **prevailing trend in simplifying the architectural structural curricula** (whilst **simultaneously putting more emphasis on the importance of structural literacy**) has been confirmed, and **adopting modern teaching methods** (mainly problem-based learning and learning-by-doing attitudes), application of which can be further supported e.g. by the opinion of an American structural engineer Fred Severud who said that: "the best way to initiate a structural feeling would be to build the structure and destroy it to see what happens" [230]. That said it should not be done at the expense of lowering the quality of structural education, therefore I see the solution in the **setting the right balance between the traditional and modern approaches**, on the **right level of constructivism in the structural education** resp. in using "enhancing" activities on the supplementary level only.
Furthermore, I see the future of structural learning in the appropriate utilisation of customised Virtual Reality applications.

[228] p. 48, year 2017-2018, chapter Technical Courses
[229] ROHLIKOVA, VEJVODOVA (2012) quoted Comenius
[230] SEVERUD (1961)

Suggested further research

During the actual running the research, I have found the studied problematics very interesting. I focused on bringing an initial overview into problematics further specialised on European English and German speaking universities, but in my opinion, the study might benefit by its **extending to other European** (e.g. France, Spain, Italy, Nordic countries...) **and world countries**. I can see as possible **engaging the exchange students** in obtaining various materials from other universities. Very important would be also participating **CTU's lecturers at various topical conferences** aimed at structural architectural pedagogues, where interesting contacts can be established and an experience shared.

The second possible way of broadening this research would be **contacting practicing architects** for their opinion on what "school structural knowledge" they are finding beneficial/ what are they missing when dealing with praxis.

Finally, I think, that pedagogues and students might benefit from the research devoted to **detailed analysis of structural textbooks** used at various universities.

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http://www.nottingham.ac.uk/ugstudy/downloads/school-brochure-pdf/architectureandbuiltenv.pdf
http://modulecatalogue.nottingham.ac.uk/Nottingham/asp/FindModule.asp
SSoA School of Architecture, University of Sheffield
https://www.sheffield.ac.uk/prospectus/courseDetails.do?id=K1002015
https://www.sheffield.ac.uk/prospectus/courseDetails.do?id=KK132015
UCC University College Cork
http://www.ucc.ie/calendar/engineering/eng007.html
UCD University College Dublin
https://sisweb.ucd.ie/usis/
UE University of Edinburgh
http://www.drps.ed.ac.uk/14-15/dpt/utsenab.htm
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UG University of Glasgow
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TUB Technical University of Berlin
https://www.planen-bauen-umwelt.tu-berlin.de/fileadmin/f6/Studieng_nge/Architektur/Arch_B_StuPO_080312.pdf
AHS Alanus University, Bonn
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FH FFM Frankfurt University of Applied Sciences
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BUW Bauhaus University Weimar
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http://www.fce.vutbr.cz/studium/programy/programy.asp?rosId=86
http://www.fce.vutbr.cz/studium/programy/programy.asp?progid=37
CTU Czech Technical University in Prague LAST VISITED: 30/06/ 2014
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http://www.fsv.cvut.cz/bk/bk2014/bc/ba.pdf
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STU Slovak University of Technology, Bratislava LAST VISITED: 02/07/ 2014
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PROF. STAFFA
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CHAIR OF STRUCTURAL DESIGN
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G APPENDICES

G1 SUPPORTING ANALYTICAL PART

G1.1 LITERATURE REVIEW

Literature review summary

To borrow a citation from Jonathan Ochshorn[231] [232], "there are probably as many opinions on teaching Structures to architectural students as there are architectural schools". Or even more (when we further build upon his idea), as we need to take into account the views of the "outside circles" represented by the specialists on pedagogy and practicing professionals both architectural and from the related fields.

Current scope of problematics revolves around several main issues, which are we going to briefly introduce bellow, and on which moreless polarised views can be documented.

The main question concerns **the importance of structural knowledge to architects,** resp. the role of structural courses in architectural curricula. With the exception of **Prof. Ochshorn**[233], who has got an **interestingly contradicting view** saying that an **architect does not need to possess a thorough understanding of structural principles**[234], arguing that:

- architects predominantly deal with small-scale designs (where member sizing is done with the help of various charts or tables)
- structural literacy is not hopelessly compromised by the architect's lack of quantitative technical competence, architect can obtain knowledge on structural design by doing similar projects or by studying similar projects by others
- basic orientation in SE problematics for communicating with specialist is sufficient (though higher level of structural knowledge is necessary for general leaders (interdisciplinary coordinators) of projects)
- as far as the design of a rational "beautiful" structures is concerned, he thinks that various quotes coming from recognised structural designers (stating the importance of structural understanding e.g. by Nervi[235]) should not be overexaggerated, and points

[231] **Jonathan Ochshorn**,
registered architect (since 1979) at New York State and professor (since 2011) at the Department of Architecture at Cornell University, USA; also taught at The Chinese University of Hong Kong and City College of new York (1980-1997), and was an associate professor at Cornell University in years 1996-2011; he lectures Building Technology incl. Structural Elements, source: Cornell University's website

[232] OCHSHORN (1990)

[233] Prof. Ochshorn is the author of several other contradictory articles (e.g. on a critique of graphical statics (2017), and a textbook ***Structural Elements for Architects and Builders*** (a practical guide for designing preliminary sizes of structural members (nomographically based)

[234] OCHSHORN (1991)

[235] **Pier Luigi Nervi (1891-1979)**,
an Italian engineer and architect; graduated from University of Bologna (1913); 1915-1918 served in the Corps of Engineering of the Italian Army; 1946-1961 Prof. of Eng. at Rome University; 1961-1962 Norton professor at

out towards the wide scientifical and often interdisciplinary based knowledge these people are endowed with, and also refers to a long painstaiking work cited (e.g. by Candela[236]) in opposition of an intuitive spur many people envisage behind the schemes.

- there is not enough time to teach students detailed structural comprehension, and simplified versions cannot mediate it (this opinion further **supports de Campoli's**[237] **views** (1983), expressing that it would be easy to reduce SE educating to the discussion over few simplified models[238] , nevertheless he does not see realistic to obtain the true structural understanding this way, let alone speak about the intuitive building creativity). **Lonmann**[239] (2001) **agrees** on the meaningless unnecessary condensation of vast amount of scientifically based structural theories into the architectural structural courses (which he attributes to the "borrowing" of an engineering approach) resulting in an oversimplified introduction into the problematics (where students only learn how to design a few basic structural elements, but do not understand the overall principles), but **on the contrary** to Campoli's view, he sees the solution in the learning-by-doing approach, promoting work with models both physical and virtual.

Harvard University; worldwide known for his innovative use of reinforced concrete; his aesthetically pleasing designs were in contrast to booming number of construction projects of that time (using concrete and steel) focusing on the potential of enginering and overseeing an architectural aspects; author of 4 books and many papers; famous projects: Olympic stadium in Rome (1960), Unesco headquarters in Paris (1950), Hangar in Orvieto (1935), source: wiki commons

[236] **Félix Candela Outeriño (1910-1997)**,
a Spanish and Mexican architect; developed thin shells made out of reinforced concrete; expert on paraboloid and hyperbolic geometry; tutor of Santiago Calatrava
graduated from Madrid School of Architecture in 1935; went to study to Germany; returned to participate in Spanish civil war in 1936, imprisoned in Perpignan camp until 1939, then put onto a ship to Mexico; 1939-49 worked in Mexico as an architect, then started working as an engineer; responsible for over 300 works in there, became also a professor in Mexico; 1971 moved to the USA; 1971-78 professor of architecture at University of Illinois, Chicago
most significant work: Pabellón de Rayos Cósmicos (1951), Palacio de los Deportes, Mexico City (1968), Mexico City metro stations: San Lázaro and Candelaria (1969), L'Oceanografic, Valencia, Spain (1994-2002), source: wiki commons

[237] Ochshorn got the quote from: de CAMPOLLI, G: ***Statics of structural components: Understanding basic structural design***, Wiley, 1983

[238] Campolli's view quoted by OCHSHORN (1991)

[239] **Bruce Lonnman**
Associate Professor at The Chinese University of Hong Kong
BArch from Syracuse University, New York, USA; BSEng, MEng, MArch from Cornell University, Ithaca, New York, USA; professional praxis at Werner Seligmann and at HNTB; teaching practice (design and structures) at various schools (Cornell, Georgia Tech, Ohio State University (USA), and at the American University of Sharjah (UAE))
source: arch.chuhai.edu.hk, visited July 2019

there is a unanimous agreement, **assigning to the position of SE subjects in architectural curricula a great significance**. The importance of the structural education in architectural curricula is explicitly highlighted by the academics: e.g. by **Wetzel** (2012), who sees it as fundamental[240], **Yazici & Yazici** (2013) who justify its relevance beside others by the fact, that appoximately 90 percent of Turkish population live in seismically active regions[241], and most structural misconceptions result in a structural failure as documented by e.g. **Akcaer & Solyuk** (2015), who specifically highlight the reinforced concrete courses at Turkish universities as vital. **Causevic** (2014) sees a good knowledge of statics as necessary for finding an ideal form of a structure, as according to him mastering statics leads to understanding the flow of internal forces[242]. **Soto-Rubio** (2017), who compared teaching methods at several North American universities also expresses his opinion directly, calling the position of structural systems and materials in architectural curricula as very important[243]. Apart from the above listed examples of immediate statements, there are also **numerous indirect accounts of the importance of SE in architectural curricula** expressed by the researchers introducing various innovative teaching approaches (around fifty papers) enhancing structural understanding, therefore classifying the structural courses as important as a result.

The second question is **the right balance** concerning the implementation of scientific apparatus (mathematical and physical formulas) into the structural courses and the actual **level of mathematical competences required**.

On the contrary to the **original concept for architecture** as a **Beaux-Arts** discipline,

[240] **Catherine Wetzel**: Associate Professor at College of Architecture at Illinois Institute of Technology, Chicago, Illinois, USA, partner at Zed Architects, graduated from University of Cincinnati (BArch.) and from University of Pensylvannia MArch), received American Institute of Architects Education Honor Award for Emerging Talent (2006) and Association of Collegiate Schools of Architecture Creative Achievement Award (2011-12, 2005-06), source: IIT's website, visited July 2019 ; see also pp.344-345 (practical example)

[241] **Gokhan Yazici:** Associate Proffesor of T.C. Instanbul Kultur University, Turkey,
Yasemin Erkan Yazici: Associate Professor of T.C. Instanbul Kultur University, Turkey - see also pp.346-347

[242] **Amir Causevic**: Proffesor at Faculty of Architecture, University of Sarajevo, Bosnia and Herzegovina, head of the Department of structural analysis and design.

[243] **Mauricio Soto Rubio**: degree in Architecture from Universidad de Los Andes, Merida, Venezuela (1999), MArch from University of Michigan, Ann Arbor, USA (2003), Assistant Professor at the School of Architecture, Planning and Landscape at University of Calgary, Canada, where he teaches Structures for Architects (previous teaching posts include California College of Arts, San Francisco, USA and IEK Stuttgart, Germany, professional practice in Venezuela, USA, England, Germany and Switzerland), co-founder and design director of Soto-architects, The Studio for Lightweight Design, source: university of Calgary's website, visited July 2019

(typical for the late 19th and the beginning of the 20th centuries, when the building was seen as an picture and the emphasis was given to the facade and to the rendered drawing, as mentioned e.g. by **Kamphoefner**[244] (1958), who recalls being taught: "...to ignore the structure as there are many engineers around, and almost everyone can tell you how to make it stand up..." or as described e.g. by **Tomovic & Sobek** (2018) such as prevailing at Moscow schools of architecture until recent days[245]),

mathematics occupied **significant position in engineering fields**,[246] especially from the time of industrial revolution at the end of the 19th century. **Gerhardt**[247] **et al.** (2003) mentions the **decline of graphostatical methods around 1890 in favour of analytical calculations**, which he attributes to the desire to rationalize engineer's work, and which lead to **disintegration of the unity of design, calculation and construction.**[248] In relation to the new technologies and structural theories, scientific approach gradually founded its way into architectural fields as well, how for example documents another extract from **Kamphoefner**'s speech introducing Salvadori's lecture on Teaching structures to architects (1958), who says that: „...**the first modern School of Architecture in the United States was established in 1937**, when Joseph Hudnut brought Walter Gropius to **Harvard**-since that the **schools have**

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[244] **Henry Leveke Kamphoefner (1907-1990)**,
champion of modernist architecture (own house in Raleigh area), the first Dean of the School of Design at North Carolina State University (1948-1973); teaching until 1979;
studied at University of Illinois (BSc.in architecture 1930), Columbia University (MSc. in architecture 1931); Certificate of architecture from Beaux Arts Institute of design in New York City in 1932; 1932-1936 private arch. practice; 1937-1948 Prof. of Archi. at University of Oklahoma
(source: wiki commons)

[245] **Ivan Tomovic**, graduated from Civil engineering at the University of Belgrad, Serbia (2002), after short professional practice returned there on research position, which he left in 2005 for the post of project manager and structural engineer in Moscow, Russia, general manager of Werner Sobek Moskwa since 2012, source: Werner Sobek's company website, visited July 2019 see also pp.352-353 (practical example)

Werner Sobek is a German architect and structural engineer, he graduated from the University of Stuttgart, Germany (1980), and finished his PhD in 1987, in 1991 he became a professor at the Leibniz University Hannover, Germany and director of the Institute for Structural Design and Building Methods, founded his own company Werner Sobek in 1992 (worldwide offices and over 200 employees now), professor at the University of Stuttgart since 1994 and director of ILEK (institute for Lightweight Structures and Conceptual Design), appointed Mies van der Rohe Professor at IIT Chicago in 2008, awarded honorary doctorate from University of Dresden in 2009, source: wiki commons

[246] see also G3 part (Short history of structural analysis), pp.362-363

[247] **Rolf Gerhardt** Prof.
RWTH University of Aachen, Chair of Structures and Structural design;
internal teaching award in 2012 for the lecture and exercise in Structural Mechanics
studied architecture at RWTH, received doctorate from RWTH (1989)

[248] GERHARDT, KURRER, PICHLER (2003)

been re-thinking their programmes to **bring mathematics, mechanics and the science of structure into sharper focus** and into clearer relationship with the design of space."[249]

Salvadori himself put a great **emphasis on a good understanding of mathematics as an assumption for learning subjects such as mechanics, structures and strength of materials**.[250]

Severud (1961) even suggested the **computations proving an understanding of both principles and stress analysis** as a **compulsory** part of students' design.[251]

Chiuini[252] (2006) cites **Ambrose** (1994) on the reducing impact of mathematics in structural courses: "One way to make structural systems part of the "intuitive" design vocabulary of architecture students is to **remove structures from the abstract realm of mathematics** and bring it into the context of building design"[253] and Alalade (2017) refers to **Muttoni** (2006), who diminishes the importance of mathematics in structural design by saying that: "knowing how to calculate and dimension does not necesarily mean that one understands the functioning, or knows how to design a structure."[254]

Hong (2011) observes, that pedagogic approaches to teaching structural principles in architectural vs. engineering programmes are almost identical, and have been like that for the past few decades. **Calculation-intensive platforms lead** in his experience to the **limited if not passive role of the students** in the teaching process[255], therefore prefers visual communication to "number manipulation".

Yazici & Yazici (2013) recall a positive experience with practical learning-by-doing structural task in their lessons, neverheless come to a conclusion that **"the most appropriate**

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[249] Kamphoefner made an introductory speech to Salvadori's talk (around 1958)

[250] cited by EMAMI (2016)

[251] **Fred N. Severud (1899-1990)**,
American structural engineer; born Fridtjov Nikolai Sæverud in Bergen, Norway; studied at the Norwegian Institute of Technology; 1923 emigrated to the USA; 1928 founded Severud-Elstad-Krueger Associates, Consulting Engineers, New York; one of the few in the world analysed the forces from and the effects of atomic bombs, source: wiki commons

[252] **Michele Chiuini**
Professor of Architecture at Ball State University, Muncie, Indiana, USA, where he teaches Architectural Design and Structural Design, degree in SE from Politechnico of Milan, Italy and MA from the Department of Architecture of the University of Sheffield, England; work experience from Italy, Japan, England and the USA, co-author of **Structural Design: A Practical Guide for Architects** (Wiley 2007), source: Ball State University's website, visited July 2019 see also pp.338-339 (practical example)

[253] CHIUINI (2006) states in his article, that this topic has been amply discussed by **James Ambrose**,in ***Teaching Structures***, 1994: New York, distributed by Wiley (unpublished manuscript).

[254] Alalade got the quote from: MUTTONI, A.: ***The Art of Structures***, Oxford, 2006, Routledge, Taylor& Francis Group.

[255] **Pyo-Yoon Hong**
Associate Professor at Southern Polytechnic State University of Oklahoma, Georgia, USA.

way to deliver the concepts of mechanics is through the mathematical abstraction", which further classify as **"absolutely essential".**

Causevic et al. (2014) strongly opposes towards ruling out the mathematical methods (in his opinion, they have got "much to offer"), therefore he sees the solution **in combining numerical and graphical methods**, with only necessary mathematical models incorporated. The purpose of the integrated numerical calculations should serve in his opinion the purpose of explaining and testing understanding.

Chiuini (2006) reports his positive experience with the use of specialised software in structural courses, but warns against the **"black box syndrome"** (when students accept practically any results given by computer). In order to improve student's rough orientation into "what range of results to expect", he sees the importance in **sizing the structural members "the traditional way"** (formulas, calculators, pen and paper), leaving only the most complex calculations to the computer.

Soto-Rubio (2017) sees the problem in courses organised by ex-cathedra engineers, who put great **emphasis on analytical techniques**, which has proved to be **problematic for students with insufficient level of mathematical skills**[256]. The high level of theoretical content[257] of these courses **does not let students apply the knowledge into their projects**, makes them stand-alone in character and might led students believe that structural and material design only comes to attention when architectural design is finished.

Vrontissi et al. (2018) also criticizes **prevailing analytic attitude to synthetic** one in "watered-down version of engineering curriculum" at architectural schools[258].

Allen & Zalewski (1998), graphostatic methods modern pioneers, do not disregard computational methods; they think the two approaches enhance each other.

The third area of interest revolves around the structural courses as such, with the following important aspects to discuss:

- when to start structural courses and how long they should take
- contents of structural courses
- the form of the structural course
- whether to aspire to design "great" structures

[256] as expressed by MC NAMARA
[257] as expressed by KHODADADi (2015)

[258] **Maria Vrontissi**
Associate Proffesor at the Department of Architecture, University of Thessaly, Greece
Diploma of Architecture Engineering (the National Technical University of Athens), Master in Design Studies (Harvard University Graduate School of Design), Doctor of Science (Department of Architecture, ETH Zurich), Peter Rice award for research in tensile membrane structures, source: University of Thessaly's website, visited July 2019

- whether to join it with a design studio

Causevic et al. (2014) suggests that students should be involved in the process of structural design (on various levels accordingly) right **from the beginning** and **throughout the whole lenth** of their studies; an opinion, that is supported also by **Allen & Zalewski**.

In the contrast to **Ochshorn** (1991), (who thinks the **students should not aim to design "the great" structures** (effective structurally and pleasing aestetically) on the basis of an argument that "only few engineers, let alone architects possess the combination of mathematical competence and an artistic intuition required", and that teachers should aim for the realistic degree of structural literacy to pass over to students), **Causevic** finds it highly **motivational** for students, and **Allan & Zalewski** raise the bar even higher targetting to **give the students confidence to create such structures** by the **means of graphic statics** (direct graphic work), which in their opinion demystifies the structures, and improves structural understanding as it offers not only the way to **analyze** the structures, but to **optimize** them as well, finally leading towards **principally similar structures with equally rational features**. According to Allen & Zalewski, students would not be able to do so with the skills taught at standard courses, where the levels of mathematics are beyond the most of them. The types of the structures, to which graphic statics can be applied range from **trusses, cable-stayed structures, funicular arches and shells to hanging cables.** Authors highlight the absence of optimalisation of such structures in a standard structural curricula. During the span of twenty years the method has been run, the students have been finding it both **easy to learn and fascinating**[259]. Further graphostatics advocates are for example **Gerhardt** et.al (2003), who in their paper highlighted the important role of graphostatics in today's lecturing and also commented upon the appropriatness of the method for **predominantly visually perceptive students** (such as architects), who are predisposed to learn in a visual way (this opinion is also supported by **Pedron** (2006) or by **Causevic** (2014)). **Gerhardt et. al** (2003) also write about the study **of Kurt Faisst** (1975), who reports that these theories have been learned easily, and memorised lastingly by students because of its illustrative quality.

[259] **Edward Allen: Architect, Structural Designer** (Boston Structures Group, designed 50+ constructed buildings), **Author** (*Shaping Structures, Fundamentals of Building Construction: Materials and Methods, Form and Forces)* , **Fellow of the American Institute of Architects. Taught at** the University of Oregon, Yale University, University of California - San Diego, Montana State University, Liverpool University, University of Washington, and MIT. recipient of the Topaz Medallion for Excellence in Architectural Education. **Source:** mit.edu website

Waclaw Zalewski (1917-2016): Polish **Construction Engineer and Designer**, Visiting Professor in Venezuela (Universidad de los Andes in Merida), consultant for the Ministry of Public Works in Caracas, 1965-1988 **Professor of Structural Design** at MIT, since 1988 **Professor Emeritus, Author** (*Shaping Structures, Form and Forces*). Source: Wiki commons

Baxter et al. (2015) write about their **experience with implementing graphic statics** into to the certain part of their structural courses at the University of St.Thomas St.Paul MN, and the University of South Carolina, Aiken, and eventhough the highly visually based **Statics Concept Inventory Exam** they run at the end did not show any statistically significant differences in structural literacy, they report that students begin to understand the engineering analysis that comes directly from the drawing, and also realize the power and usefulness of a free body diagram. Graphic To name a few examples, graphic statics based lectures are run at MIT Boston, ETH Zurich, RWTH Aachen, Germany or at Cambridge University, England. An interesting **critical voice towards graphic** static application in lecturing has been casted by **Prof. Ochshorn**, who finds the method clever, but cumbersome, with no justification in nowadays computer era. He points out that the **relationship between geometry and force is visible, but causal relationship remains obscured,** and that graphical methods has been devised and used more as the practical tools than as a windows into behaviour. He further questions the validity of results when graphical methods **do not distinguish between members in tension and members in compression subject to buckling** (their design is therefore independent on internal force as Eulers critical buckling stress is determined by modulus of elasticity, radius or gyration and an effective length and not by material's allowable compressive stress), therefore sees no logic in assuming that an optimal form can be determined from the analysis of forces in the types of structures in compression. He supports his views further with a case study of optimal truss design, where graphic statics method has been proved as ineffective.

One of the problems of **architectural structural courses** according to **Chiuini** (2006) is their **separation from the reality**. Chiuini sees structural design **not as an exact discipline, but as a skill** requiring initial assumption generated from experience, and thinks that students should expect an iteration process before getting to the final result. He puts an emphasis on the necessity of the **structural solution being proposed simultaneously with the architectural design**, which can be done either by making structural courses integrate part of the studio or by teaching the structures "around the building project". His view further supports by **Bender's quote** (1994) concerning methods of teaching structures to architects and their outcome: "The **classical sequence of presenting statics, strength of materials, analysis and 'design'** may represent a logical progression of information. However, divorced as it usually is from involvement with the total process of design, this **sequence has resulted in architectural graduates who have no understanding of the basic principles involved, cannot apply them, nor retain for a significant period after graduation the basic core of material encountered**." They have successfully adopted the first possibility at the University of Ball, Indiana, as described earlier[260]. Incorporation of applied sciences into studio is supported also by **Schon** (1988), **Emami** (2016)[261] or **Soto-Rubio** (2017); the "**second studio" (technological)** is suggested by **Allen**[262], who thinks it helps to improve the efficiency of learning. Successful incorporation of structures into the studio reports also **Wetzel** (2012) with a project developing and broadening structural inteligence (an active experimentation with large-scale structural models) at the University of Illinois. Ochshorn contributes to the discussion with a historical insight reporting that **Smith** (1987) or **Gropius** (1955) **saw the need of the integration**, and adds a quaint example in the form of the analysis by the Deans of the Consortium of Eastern Schools of Architecture[263] (1981) commenting on failure to do so. **Ochshorn** himself **does not see** the actual **separation as a weakness**, and provides an interesting analysis of the **relation between Structures and Studio** from the **historical angle**.

<u>On physical models within structural architectural courses:</u>

Severud (1961) said that **structural principles cannot be learned if they are not applied**, and suggests "recasting the ideas in fresh combinations" so the students would remember them. According to him, the best option would be to build the structure, destroy it and let the students see what hapens.

According to **Lonnman** (2001) who refers to **Engel** (1972), it is necessary to clearly distinguish between engineering and architectural approach to teaching structures, an argument supporting the need of an alternative attitude. This view is shared e.g. by **Pedron** (2006), who highlights the differences in the perceptions of particular professions (architects show predominantly visual learning abilities) resp. recommends visually based learning activities for architectural students.

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[260] **Michele Chiuini**, see fn.252, and pp.338-339

[261] **Niloufar Emami**
Associate Professor at Lousiana State University, USA; researcher, educator and designer; completed her PhD studies at the University of Michigan (Architecture with specialisation in Building Technology), in her own words, she seeks the overlaps between architecture and multiple engineering disciplines and uses computational tools in order to provide creative yet performative solutions, received LSU Tiger athletic Foundation Undergarduate Teaching Award in 2020, source: niloufaremami.com , visited July 2019

[262] ALLEN (1997)

[263] Architecture Education Study, Vol. I Consortium of East Coast Schools of Architecture, 1981,
p.828 ("We have, to start with, failed to find practical ways to integrate non-studio course material into the studio/workshop exercises..."); source: OCHSHORN (1991).

Khodadadi[264] (2015) refers to **Prince**[265] on the **inability of students to maintain their attention**

during lectures, further supported by the findings of **Palio** (attentiveness at lectures is only around 60%; doing the real things allows us to understand and remember almost 90% of what we are taught), **Silverman** (even whilst concentrating, students listen to only about a half what the teacher is saying; brains do not work as an audio or video tape, information needs to be processed, questioned, tested and categorised prior to being saved), **Ruhl** (recommends making connections to what is already known during the transmission and refers to the better brain function during discussions) or **Holt** (claims the learning is more efficient when there is an opportunity to see the connections, process them into formulating consequences, and state them in own words). She also brings into attention **Silberman's modification of Confucius quote**, which correspons with **Dale's Cone of Learning**, showing the ability to memorize concepts increasing with participation in practical tasks. On the basis of the above listed, she suggests **accompanying activities**, which would simultaneously improve structural understanding, and point out towards **the incorrects assumption that adult learners do not require** experiments or **heightened activities during the learning process** (because of their ability to understand abstract subjects).

Examples of the **universities that has implemented learning-by-doing experience** (working with small-scale physical models) **in their structural curricula** are: University of Oregon, USA (Plesums, 1974), University of Sydney, Australia (Cowan, 1982), Jaume I University in Castello, Spain (Romero & Museros, 2002), ETH Zurich (Pedron 2006), RWTH Aachen, Germany (Gerhardt, 2003), Ball State University, Muncie, Indiana, USA (Chiuini 2006), University of Hong Kong, China (Lonnman), Southern Polytechnic State University, Oklahoma, USA (Hong 2011), Illinois Institute of Technology, Chicago, USA (Wetzel 2012), Virginia Tech Blacksburg (Setareh et al, 2012), Istanbul Kultur University (Yazici & Yazici, 2013), Wroclaw University of Technology (Ogielski et al., 2015), Taubman's College of Architecture of the University of Michigan, USA (Khodadadi 2015, Emami 2016), California College of Arts, San Francisco, USA, the University of Minnesota, USA, Syracuse University, USA, Montana State University, USA, Faculty of Environmental Design of

[264] **Anahita Khodadadi**
Associate proffesor at Portland State University, USA;
BArch from Universitz of Tehran, Iran (2008), MArch from University of Tehran, Iran (2010), M.S. in Architecture and PhD in Architecture from Taubman College of Architecture and Urban Planning, University of Michigan, USA; researcher, designer, educator
source:anahitak.com, visited: July 2019

[265] M. Prince, "Does Active Learning Works? A Review of the Research," Journal of Engineering Education, vol. 93, no. 3, pp. 223-231, 2004.

University of Calgary (Soto-Rubio 2017), Moscow Architecture School (Tomovic & Sobek, 2018), University of Oklahoma (Callahan et al. 2019).

The **only unfavourable comment on the presence of the models within the structural courses for architects** has been found in **Ochshorn's article referring to Campoli's** refusal of them for bagatelizing the otherwise complex structural problematics.

Although naming **some (mostly organisational and time related) disadvantages** in connection with using the models, out of the approximately fifty scientific papers, there was a **unanimous positive experience reported**. Tutors see the models as an appropriate way to **complement** their lessons (not replace), giving them relatively high educative value for their **clarity** and both enjoyable and motivating **explorative character**. What slightly differs is the degree of complexity of particular activities i.e. creativity with which particular tutors approach the experience, although very often the creativity comes predominantly from the students' side as they have to fullfill various open assignments.

Another example of the work with physical models is represented by construction workshops, where students work with the **large-scale structures** (usually create them). The most significant experience we have come across is the project at Illinois Institute of Technology, USA, as reported by Wetzel (2012). Other examples were found at the following universities: University of Cambridge (England), Technical University Munich (Germany), CTU Prague (Czech Republic), HCU Hamburg (Germany), ABK Stuttgart (Germany), MIT Boston, USA to name just a few.

On the use of ICT and the virtual modeling

The actual implementation of ICTs technologies (in the form of various software applications) is described in the part discussing innovative approaches to learning, and throughout the part devoted to the Case studies where applicable.

Related scientific papers overview:

One of the first experimental test-running of specialised software within the architectural structural tuition is reported by **Black & Duff** (1994), who describe their experience (custom made visual environments were developed to demonstrate complex concepts) at the University of California, Berkeley, USA.

Lonnman's paper (2001) is informing on the use of both **demonstration and interactive** digital **models for structural tuition at Hong Kong University** in China, with three types of models distinguished (form models, behaviour models and analog models). Features the program offers to its users are described (e.g. 3D visualisation, demonstration of buckling, measurement of strain and deflection, determination of ultimate load capacity...).

Learning-by-doing project at the Jaume I University in Castello, Spain complemented by computer simulations (using program SAP 2000) offering structural analysis and iteration structural design process is reported in detail in **Romero & Museros** article (2002).[266]

Gerhardt et al. (2003) appraise digital possibilities concerning iteration processes connected with graphic statics implementation.

Steif[267] and Dollar[268] (2005) from Carnegie Mellon University and Miami University in the USA introduce their concept called "Learning Modules for Statics" - a fundamental class on how objects and forces behave, accompanied by computer presentations.

Elaborate account of the features and functions of Easy Statics Programme, developed by **Pedron** [269](2006) at ETH Zurich is given in her dissertation.

Chiuini (2006) refers to his experince with implementing specialised software into structural studio course. According to him, **understanding of structural behaviour** can be **significantly facilitated by the use of structural analysis software**, which allows students test alternative configurations. To reduce the **"black box syndrome"** mentioned earlier, Chiuini recommends to use the computer software only after the students have been introduced to the basic structural knowledge in classic lectures. The use of the software is reported to be one of the proposed innovations to the course, resulting in overall **improved efficiency** of the course (less modules needed, curriculum broadened with statically

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[266] see pp. 69-70 for description of activities and pp. 348-349 for additional info

Manuel L. Romero, Prof.
PhD from Construction Engineering Department of the UPV (Universitat Politécnica de Valéncia) 1999, research stays at University of California at Berkeley, the director of the research institute ICITECH
Pedro Museros, Assoc.Prof.
Universitat Jaume I 1998-2003, mechanical and structural engineering; Universidad de Granada 2003-2010, doctorate in structure dynamics; Universitat politechnica de Valencia from 2010; Dpt. of Continuous Medium Mechanics and Theory of Structures

[267] **Paul S. Steif** received undergraduate and graduate degrees from Brown University and Harvard University in engineering mechanics. He is currently Professor of Mechanical Engineering at Carnegie Mellon University. He has been active as a teacher and researcher in the field of engineering mechanics, for which he has received a number of awards. Steif is currently involved in research studying student learning in basic engineering subjects, measuring student conceptual progress, and constructing educational materials that facilitate learning. Many of these developments have reached an international audience, including educational software which is published with widely selling textbooks. source: author's paper

[268] **Anna Dollar** received both her Master's degree and doctorate in applied mechanics from Krakow University of Technology in Krakow, Poland. She was an Assistant Professor at the Illinois Institute of Technology in Chicago, and is currently Associate Professor at Miami University in Ohio. At IIT she received the departmental Excellence in Teaching award, and the University Excellence in Teaching Award. At Miami she received the School of Engineering and Applied Science Outstanding Teacher award. Her research focuses on the mechanics of solids and engineering education. source: author's paper

[269] **Claudia Pedron,** PhD candidate at ETH Zurich in 2006

indeterminate structures, which would not have been possible without computer analysis). Chiuini also expresses his opinion on the necessity of **thorough assessment of any specialised software used**.

Lonnman (2007) penned another study on the problematics of incorporating computer software into structures courses (related to the American University of Sharjah, UAE), and accompanied it by illustrative examples. He explicitely highlights the advantages of switching various levels of digitalised structure on/off, trying various structural systems on given assignment and "see through" mode.

Hong (2011) from the Southern Polytechnic State University in Marietta, Georgia, USA, gives a thorough account of showing how he based his concept of "sweetening structural principles for students" on interactive lessons widely using the advantages of computer simulations (e.g. as an introduction into problematics, students participate in "race of different sets of forces" program, or interact with visually based explanation on the moment of force and concept of excentricity)[270]

Setareh et al. (2012) describe the situation at Virginia Tech Blacksburg and introduce software program **SAFAS**, which **can comprehend the relationship between the structure and its form**.

Digital animation models are highly praised by **Causevic** et al. (2014) for the ability to explain almost all statics principles more effectively and straightforwardly. According to team, they give the learner the possibility to explore the structures by observing various results (which are quicker and more accurate), and are atractive to work with. FEM methods are also thought as a big advantage as they give the detailed analysis of stresses and deformations.

Emami (2016) puts computer-based simulations, virtual reality and web-based interactive structural education on the list of activities reinforcing intuitive structural understanding. **Computer based simulations and virtual reality** part is devoted to informing about the FEM (finite element analysis) and numerical methods based software producing structural behaviour analysis. With the help of some of them, the user can follow real-time results (internal forces and reactions; sometimes even required materials or costs). She refers to **Mueller**'s [271] article to name the examples: **"Arcade" by Martini, "SAP2000" "DrSoftware" and "Force Effect" by Autodesk.** As for disadvantages of these systems, she refers to **Preisinger**[272], and sees the amount of time needed to master these programs as the main setback, together with the fact, that students with no insight into problematics **trust any**

[270] see pp.356-357 for more info

[271] MUELLER, C.T., 2014. Computational exploration of the structural design space . MIT. Source: EMAMI (2016)

[272] PREISINGER, C., 2014. Parametric structural modeling. , pp.1–104. Source: EMAMI (2016)

outcome (cannot distinguish between clearly correct and incorrect values). She recommends architectural modeling tools like **Karamba (plug-in for Rhino NURBS**). As far as the Virtual Reality is concerned, she describes the University of Michigan's **3d Lab CAVE** (3x3m Computer Assisted Virtual Environment), where students can interact with the structures and see how they collapse from various perspectives. As for **web-based interactive education**, she names Easy Statics (Claudia Pedron), eQuilibrium (Block Research Group) or NovoEd (Demi Fang & team) as examples of teaching programs.

Tomovic & Sobek's (2018) paper on teaching structures at Moscow school of Architecture assesses the impact of digital modeling as positive and of great significance. The paper shows real examples, how they complement hand-on methods with computer-based analyses.

<u>On the AR and VR</u>

Scientific papers on the problematics of Virtual and Augmented Reality:

At the moment, there are two noteworthy academic teams devoting their attention to a research in the field of accustoming virtual reality interface to structural exploration.

The first team consists of following researchers[273]: Yelda Turkan (Oregon State University, Corvallis, USA), Rafael Radkowski, Aliye Karabulut-Ilgu and An Chen (Iowa State University, Ames, USA), and Amir H Behzadan (Texas A&M University, College Station, USA). The findings of **Turkan**'s team **(2017)** can be briefly summarised as follows: their previous reasearch has shown the **deficits in students' understanding of behaviour of structural parts in 3D context**, which has been in their opinion caused by the **shortcomings of traditional lectures'** approaches, putting too much emphasis on the analysis of individual structural members and not providing holistic approach to the analysis of more complex structures. One of the key problems is for example represented by the fact that many students are not able to see the relation between the static schemes and the real structures.

By the incorporating **mobile augmented reality AR and interactive 3D visualisation** they aim to illustrate **behaviour** of virtual structures **under different loading conditions**. Students can change the loads and get instant feedback on reactions and other properties, which they can observe. The paper informs of an undergoing study at junior levels, aim of which is to find the most appropriate ways for the use of the device. Pre- and Post- tests are regularly taken to assess the impact of the teaching approach.

Turkan's et al. (2018) second paper is devoted to the problematics of implementing AR into teaching process of structural design. They inform about researching students' choices:

[273] at the time of paper publishing 2017

whether they would like to be guided when solving structural problem, or whether they would rather explore the virtual structure via the means of application on their own. Although the test results were inconclusive, a slight inclination toward individual explorations has been observed.

The application is called **iStructAR** and is for Apple and iPad and is currently tested in SE courses.

The second team engaged in virtual reality research in connection with structural education comprised of following researchers[274]: Gregory Charles Quinn (Swinburne University of Technology, Melbourne, Australia[275]), Christoph Gengnagel, Adrian Galleazzi, Fabian Schneider (Berlin University of the Arts, Germany).

The first augmented reality[276] gadget they developed born name **StructAR** and worked in 2D and it allowed to watch changing internal forces on structural model according to changing external loads. The model was made out of GFRP[277] rods joined together and pinned onto projection board, interaction between the physical objects and digital simulation was done by tracking printed fiducial markers utilizing optical web camera as well.[278] Softwares used for the simulation were: Kangaroo dynamic relaxation (DR) solver and the Rhino/Grasshopper. StructAR works in 2D.

The next system the team has developed is called **StructVR** (virtual reality based), developed as a teaching tool giving the user an opportunity of a virtual interaction with the structure together with the possibility of inflicting its deflection and then observing how the internal forces and reactions are distributed, and examining the structure's defformation pattern.[279] There is also a mode allowing the user create his own structure. Software used for realisation: Rhino/Grasshopper, dynamic relaxation solver Kangaroo and Unity. There is also an early prototype **StructMR** (mixed reality) gadget.

The scientific paper (2019) of Jordanian team of researchers[280] from the College of Architecture and Design at Jordan University of Science and Technology is focused on general building construction interaction.

[274] at the time of paper publishing 2018

[275] Dr Quinn was afiliated to UdK Berlin in 2017 when the paper was published

[276] projection of the images created by synchronous simulation of the same system

[277] glass fiber reinforced polymer

[278] see pp.332-335 for detailed description

[279] The types of structures, for which the system can be used are for example: a portal frame, a truss, a bridge, a cantilever, a towerů more info about the system see page

[280] A.K. Bashabsheh, H.H. Alzoubi, M.Z.Ali

As already mentioned, the University of Michigan disposes with 3d Lab CAVE giving the students possibility to interact with the structures, though at the time of paper publishing (Emami 2016), it was for engineering students only.

Literature review conclusion is located in the main part of this study.[281]

[281] see p.33

G APPENDICES

G1 SUPPORTING ANALYTICAL PART

G1.2 HIGHER EDUCATION DIDACTICS

Transmissive vs. constructive attitude

According to **Zormanova** (2012), the **school is rather conservative instituition** that **tends to maintain an existing concept** and established methods of teaching, however the teaching method is a dynamic element that changes faster then the teaching concepts or organisational forms, as it is influemced by the teacher's attitude to learning, overall concept of teaching in the society of given time and other didactic elements.

The two main approaches to teaching are transmissive and constructivist.

The **transmissive teaching** contains following teaching concepts:

1. **dogmatic**, which corresponds to the medieval teaching through the passing knowledge
2. **verbally-presented**, with the focus on the visual clarity (Comenius)
3. **verbally-reproductive**, based on memorisation without prior understanding (Johann Friedrich Herbart)

The **constructivist teaching** was introduced by John Dewey and its main concept links the school learning with an **applying the knowledge in the real-life situations** (problem learning).

TRANSMISSIVE TEACHING

Teacher-Centered Instructional and Behaviourist approach

Orlich et al.[282] (1998) states that when described by the behaviourist theory, learning can be viewed as a cycle of stimuluses from teacher, closely followed by a response actions from learners. It is the **teacher**'s choice what he „**transmits**“, **students** are only **passive recipients** and their role is reduced to memorize and absorb delivered facts, then later “regurgitate” them during the exam. Active participation of students in the learning process is not encouraged. This method furthermore **promotes individualism and competition** and assumes that students learn all in the same way. Unfortunately, relatively high percentage of students taught in this way **cannot solve the real life tasks** they encounter.

[282] ORLICH (1998); source: Pedron (2006)

Kalhous, Obst[283] (2002) characterize the transmissive teaching as a process, for which is typical to use teaching strategies that **give students ready knowledge and skills and lead them directly to gaining them**, and agree on students' roles of passive recipients.

Pecina, Zormanova (2009) portray transmissive teaching as a traditional (classical) teaching that is **focused on curriculum and its content**. The dominat role is taken by a pedagogue, who concentrates on fulfilling the criteria of explaining all topics included in curricula, and **does not have much time to concentrate on pupil and his needs** (whether he actually understands the lectures, whether he is motivated...), and refer to typical features of traditional teaching as compiled by Okon:

Typical features of traditional teaching according to **Okon** (1966)[284] [285]are:

- **teacher concentrates on teaching curriculum** and its contents, pupil and his needs, abilities, coping with the curriculum stay aside, teacher does not have time to deal with it
- **predominance of the interpretation method**, when teacher submits pupils to complete knowledge, which they learn from him or from textbooks
- **an easy emergence of the unexpected difficulties or obstacles** (e.g. use of the word not known to pupils), typical is also momentarily unattention of students
- **impossibility to adapt speed -** teacher uses the same pace for all (most often according to average or weaker pupils)
- **difficulty to control knowledge** of students

Traditional teaching methods according to Manak, Svec (2003) can be:

- **verbal methods**
  (e.g. interpretation, narration, explanation, description, lecture, work with text, interview)
- **demonstration methods** (e.g.demonstration and observation, work with text, giving instructions-briefing)
- **practical-skills methods** (e.g.imitation, manipulation, production methods)

Leading position has the interpretation method, which is usually combined with the description method or with the demonstration method. Organisational form is mainly **frontal**. [286]Althoug generally criticised, **Pecina, Zormanova** (2009) see positive in the fact that

[283] KALHOUS, OBST (2002)
[284] OKON (1966); source: ZORMANOVA (2012);
[285] **Wincenty Okon** (1914-2011), Polish pedagogue, highlighted the importance of not concentrating on pure theory, but including practical and emotioanal aspects into teaching;
[286] see p.210 for detailed info

knowledge of students is presented in a coherent system. According to them, it is appropriate to use the **traditional instruction method in the following situations**:

- to conwey a difficult to understand complex substance that requires a broader knowledge of other areas and professional subjects
- to mediate an abstract curriculum
- to convey the rules (especially in language teaching)

Zormanova (2012) points out towards a **very intense critique of traditional teaching in contemporary pedagogy literature** [287] and says, that the long tradition of criticism dates back to the 19th century, to the beginnings of the reform movement, which is associated for example with **Ellen Key[288], John Dewey[289], Rudolf Steiner[290], Maria Montessori[291], Peter Petersen[292], Helen Parkhurst[293] and Celestin Freinet[294]**; and refers to the summary of these views in **Skalkova** [295] (1971), who states that **tradional teaching** based on reproducting of ready knowledge is **not sufficient**, because there is **no preparation for solving life problems**. On the contrary to innovative methods when pupils take active part in learning, they formulate hypotheses, develop their imagination and intellectual properties.

Rohlikova, Vejvodova (2012) point out towards **Skalkova**'s[296] (2004) more recent expansion of the original view saying that it is possible and effective to **reject the traditional and to wellcome the modern** pedagogy, but such attitude **represents considerable simplification**, and also cite **Savage, Roccio**[297] (2005) on the need to **provide the best possible external conditions for learning** based on the instructivist concept seeing the external conditions as predominant in forming the learning process. The learning process as such is seen as **linear**

[287] Zormanova cites following authors: Prucha (2001), Svobodova et al (2007), Strelec at al. (2005), Bertrand (1998)

[288] **Ellen Key** (1849-1926): Swedish feminist, writer on many subjects in the fields of family life; early advocate of a child-centered approach to education and parenting; source: Wiki commons

[289] **John Dewey** (1859-1952): American philosopher, psychologist and educational reformer; his ideas have been influential in education and social reform; source: Wiki commons

[290] **Rudolf Steiner** (1861-1925): Austrian philosopher, social reformer, architect, economist, esotericist; established **Waldorf education**; source: Wiki commons

[291] **Maria Montessori** (1870-1952): Italian physician and educator best known for the philosophy of education that bears her name, and her writing on scientific pedagogy: source: Wiki commons

[292] **Peter Petersen**: German pedagogue, head of the Department of Education at the University of Jena; author of the teaching concept **Jena Plan** (1923-1927); source: Wiki commons

[293] **Helen Parkhurst** (1886-1973): American educator, founder of the **Dalton School**; source: Wiki commons

[294] **Celestin Freinet** (1896-1966): French pedagogue and education reformer; created the teachers' trade union from which Modern School Movement in France arose; Freinet promoted enquiry-based learning and cooperative learning; source: Wiki commons

[295] SKALKOVA (1971), source: ZORMANOVA (2012)

[296] SKALKOVA (2004), source: ROHLIKOVA, VEJVODOVA (2012)

[297] SAVAGE, ROCIO (2005); source: ROHLIKOVA, VEJVODOVA (2012)

process, where every new step is directly related to the previous one. The teacher provides the information (usually supported by examples and rules), and the students are expected to absorb the theoretical knowledge and eventually deepen it by going through pre-set exercises.

CONSTRUCTIVISM

Student-Centered Instructional and Constructivist approach

Constructivist theories represent an attempt to overcome the transmissive theory; **Bertrand**[298] (1998).

The basic idea of humanistic psychology and constructivist concepts is that learning is **not something that is done on students**, but **what students actively do on their own**. Student's activity is not conceivable without his / her inner motivation to learn, which can be encouraged by external motivation (eg from old age family, teacher ...), **Rohlikova Vejvodova** (2012).
In connection to the students's "own work" mentioned above we need to emphasize the social dimension of the constructivist concept as students **form their own views by confronting them with the views of others**. **Woodfolk**[299] (1993), however the resulting **structure of knowledge** and attitudes is **highly individual** for each student as said by **Nezvalova**[300] (2005).

Constructivists focus on how the **learning process is conditioned by level of student's abilities and his previous knowledge and also on the process of learning itself**. Constructivists think that learning is necessary to study as teaching to a specific content, they are focusing on subject didactics and psychodidactics, **Pecina, Zormanova** (2009).

Constructivist approach to teaching presupposes the use of appropriate teaching **strategies** i.e. those that activate and guide the pupil's cognitive processes **to develop independence, imagination, logical thinking and creativity**.
Constructivist conception of teaching is connected with complex and activating teaching methods such as **dialogue, discussion, problem method, brainstoring, didactic games, staging and situation methods, project teaching, group and cooperative learning, critical thinking, open learning, learning in life situations**.
Manak, Svec (2003)

[298] BERTRAND (2005), source: ZORMANOVA (2012)
[299] WOODFOLK (1993) source: ROHLIKOVA, VEJVODOVA (2012)
[300] NEZVALOVA (2006), source: ROHLIKOVA, VEJVODOVA (2012)

At the present time, the learning-centered model of education is considered as more appropriate, because it helps to develop skills such as critical thinking, ability to solve problems, work in a team and communicate. **Pedron**, (2006).

Pecina, Zormanova (2009) further state, that although the constructivism in pedagogy is very popular, there are several voices **criticizing** its **low level of effectiveness**, especially when acquiring complex knowledge is targetted, and points out that a **complete replacement of traditional "proven" practices might lead to the deterioration of overall educational system**. In their opinion, **both attitudes** (instructivism, constructivism) **should be appropriately combined -** a view that is also supported by e.g. **Tracey**[301] (2009) who thinks that **overall constructivist concept** of learning apriori **does not dismiss** the presence of **instructional parts** within.

Rohlikova, Vejvodova (2012) are also sceptic as far as an unconditional support of constructivism is concerned for the reasons that: **students cannot discover what has already been discovered**, mostly there is a **necessity of scientific approach towards** particular **subject**, and finally there is **not enough time** to realize the subject on primarilly constructivist concept, therefore support to **combine both attitudes** in the learning process.

Development of teaching methods (short historic overview)

In the **ancient Greece and Rome**, the most popular teaching methods were **lectures**, **dialogue** (Sokrates) and **didactic game** (Plato, Aristotle). Roman educator Marcus Fabius Quintilianus recommended following steps in learning: imitation, theoretical lesson, practical exercise.

In the **Middle ages** (European culture) **dogmatism** and **scholastic approach** (memorisation of church texts) prevailed, however method of **disputation (scientific debate)** was very popular and more **practically oriented town schools** appeared.

The **first modern pedagogy efforts** (to limit theoretical, mostly memorable learning) can be traced to the **Renaissance period** (14th-16th century), with the later **real changes in organisation of education** being connected with **Comenius**[302], who preferred natural method

[301] TRACEY (2009): source: ROHLIKOVA, VEJVODOVA (2012)

[302] **John Amos Comenius** (1592-1670): Czech philosopher, pedagogue and theologian; considered the father of modern education (concept described in his book ***Didactica Magna*** *(The Great Didactic))* as an educator he led schools and advised governments across Protestant Europe through the middle of the 17th century; besides his native Bohemia, he lived and worked also in Sweden, Polish-Lithuanian Commonwealth, Transylvania, England, the Netherlands and Hungary; source: Wiki commons

(derived from cognition of nature and its imitation), and formulated the new conception of teaching (**promoting illustrative aspects, systematicity, engaging senses, requiring examples, rules and practice**). At the beginning of the **19th century**, **Herbart school** was the most influential one (teaching took four stages; methods of of **interpretation, explanation, description, demonstration methods, work with textbook and book as well as various exercises** that helped fix the subject matter were used), further leading to memorial learning and the passivity of students. Reform efforts came at the beginning of the **20th century**, where an emphasis was put onto the student's independent activity and teaching methods such as **interview, discussion, problem method, project method or laboratory work** and **practical activities** were preferred. One of the main critics of Herbart school **John Dewey**[303] came up with so-called **pragmatic pedagogy**, the center of which is a child. His concept represents the starting point for **problem and project methods of learning**, on which his "**working school**" is based. "**Learning by doing**" represents the opposite to a passive listening or memorisation. Other promoters of working school concept were for example **Georg Kerschensteiner**[304], or the founder of a well-known **alternative school Celestin Freinet**.[305] Further examples of alternative education are represented by e.g. **Dalton Plan**[306], **Jena Plan**[307], and **Montessori**[308] or **Waldorf**[309] education.

[303] **John Dewey (1859-1952)**: American philosopher, psychologist and educational reformer; the overriding theme of his works was profound belief in democracy; Dewey considered two fundamental elements -schools and civil society- to be major topics in need of attention and reconstruction to encourage experimental intelligence and plurality; source: Wiki commons

[304] **Georg Kerschensteiner** (1854-1932): German educational theorist; director of public schools in Munich (1895-1919); later professor at the University of Munich; developed pragmatic approach to education that included the integration of academic study with physical activity; source: Wiki commons

[305] **Celestin Freinet** see fn 294

[306] **Dalton Plan** is an educational concept created by Helen Parkhurst inspired by the intellectual ferment at the turn of the 20th century; the aim was to achieve a balance between a child's talent and the needs of the community; source: Wiki commons see also fn 293

[307] **Jena Plan**: see also fn 292

[308] **Montessori education**: a child-centered educational approach based on scientific observations of children; source: Wiki commons; see also fn 291

[309] **Waldorf education** is based on the educational philosophy of Rudolf Steiner, who founded Anthrosophy. Its pedagogz developes pupil's intellectual, artistic and practical skills in an integrated and holistic manner; he central focus is creativity; source: Wiki commons

Forms and methods of teaching in Higher education

There are currently two main modes of studies at the universities: **full-time** and **part-time**, however not all the courses have a part-time option. There is usually also a possibility of a **flexible study**, which students organize individually according to their specific needs in collaboration with particular university and college.

The full-time study is the more "standard" one, when students spend most of their time on the campus. It gives them better chance to assimilate the information, to practice and to repeat the taught material, and permanent contact with other students gives them more options to discuss subjects, exercises, homework, as well as the chance to build up a future business network. Full time students have various financial privileges, but because of having no job or only occasional short-term jobs, they usually depend on someone financially. As a consequence of busy teaching schedule, they graduate with a lot of theoretical knowledge, but with only a limited practical experience, which is disadvantage whilst applying for a job. Part time study usually lasts longer than full time.

As far as the **forms of teaching** are concerned, the basic classification can be done **according to the organisation** (frontal, group, individualised, combined), or **according to the type of the course** (main methods (lecture, seminar, project, exercise), complementary methods (praxis, excursion, selfstudy, consultation...). The types of courses are listed and defined in study regulations of particular universities.

The **methods of teaching** can be further classified as follows:

- presentation and demonstration
- discussion
- cooperation (partner or group)
- project solving
- problem solving, research methods
- simulation, situation and inscenation methods

FORMS OF TEACHING ACCORDING TO THE ORGANISATION

FRONTAL LEARNING

Frontal teacher-centered instruction style of learning commonly refers to lessons, where the teaching activities take place in front of the classroom.[310] It is a mass education, where students either receive uniform learning content, or work simultaneously according to the teacher's instructions. Central role of a teacher is typical as well as one-way communication from the teacher to students.

Mutual communication is possible for an interactive concept.[311] A typical and the most common example of the frontal learning is a **lecture**.[312]

GROUP LEARNING

Organisational concept of the group learning is based on **social learning**[313] and **peer cooperation**. Students work in small groups (3-5 people) formed spontaneously or from the teacher's initiative - teams might be put together according to the various criteria (e.g.by the character of the task or its complexity, by their performance level, their learning pace...).

Within created groups, students can **discuss their tasks, divide the work, work together towards the goal, suggest different methods of tackling the problem, provide mutual control, find some mistakes, and get an instatnt feedback or some explanation from their peers.**[314]

Group learning is closely connected with the term **cooperative learning**[315].

Vasutova (2002) sees the **main advantages** in an active gaining of lasting knowledge and skills, praises the **motivation** (stimulant learning atmosphere with no fear or stage-fright leads to a strengthening of a positive attitude towards learning), and values positively **social aspects** (development of communication skills, team work support, an opportunity for a self-reflection and a peer comparison).

As for **disadvantages**, Kasikova (2010) names **not an easy to keep systematisation**, the **risk of straying away** from the original task, an **unequal distribution of work** betweeen the

[310] source: Wiki commons

[311] ROHLIKOVA, VEJVODOVA (2012)

[312] see pp. 211-217 for detailed info

[313] **Social Learning** Theory; by Albert Bandura; people learn from one another, via observation, imitation, and modeling; the theory has often been called a bridge between behaviorist and cognitive learning theories because it encompasses attention, memory, and motivation;
source: https://www.learning-theories.com/social-learning-theory-bandura.html
visited: July 2019

[314] see p. 210 for detailed info

[315] see p.228 for detailed info

partipcipants (a clash of "ambitious" vs. "lazy" team members - ambitious people either do most of the work because of unwillingness of others to help or because of not being satisfied with a quality of work produced by their peers, or what might happen is, that the most ambitious people of different groups compete between themselves and do not care about their own groups), **some mistakes take longer to spot** and correct. Also, if the groups work runs during the classes, it is an **organisational challenge** for many reasons: students do not perceive the group work as a "serious" learning, therefore tend to be noisy, the groups work in a different pace, and usually the overall amount of topics studies is not as big as if it was introduced to students traditional way. Therefore a proper preparation is essential, and tutor should evaluate the appropriatness of the method for a particular situation.

INDIVIDUALISED LEARNING

Individualised learning is **customised for each student in accordance with his capability**, and is generally expected that every student is going to make an effort adequate to his abilities. Therefore the students often work on the different types of assignments. The students are given a space for their own activities, which include a selfstudy, and take responsibility for their own progress and results of their work. **Individual consultations** are given to each student by the tutor; students are also influenced by their peers.[316] A typical example of individualised learning is a **project**.

COMBINATION

of all the above listed options is also possible within a particular subject.

FORMS OF TEACHING ACCORDING TO THE TYPE OF A COURSE

LECTURE

is defined as an "**oral presentation** intended to present information or to **teach people about particular subject**, for example by a university or college teacher. The noun "lecture" dates from 14th century, meaning "action of reading, that which is read," from the Latin lectus, pp. of legere "to read." Its subsequent meaning as "oral discourse on a given subject before an audience for purposes of instruction" is from the 16th century. The verb "to lecture" is attested from 1590." [317]

[316] source: ROHLIKOVA, VEJVODOVA (2012)
[317] source: vocabulary.com website, visited July 2019

Lecturer not only presents a certain topic, but also **analyses** interdependencies between singular aspects, **reasons** his or generally recognised points of view, **provides evidence** of the statements if necessary, **and assessments** as well[318].
Characteristic properties of a lecture according to Vasutova (2002): the lecture should be structured and coherent, is supposed to show clarity, recency, and an appropriate difficulty as far as metodology and content are concerned. The lecture is typically intended for tens to hundreds of listeners, and usually is accompanieded by other types of the knowledge transfer as well (typically more practically orientated or with an attention to a detail-e.g. exercises). Desirable is also an addition of a complementing visual material, which further illustrates the topic.

As stated by Vasutova (2002), people typically **connect the term lecture with a monologue** of a significant person on a serious scientific theme, but monologue should not be university lecture's objective; preferable form would be of a dialogue, enriched of some students's activities within.
Typical example of a dialogue would be an interactive lecture based on questions and answers, discussion, or cooperation in a **problem solving**. That mentioned requires a coordination-experienced lecturer, who introduces the problem at the beginning of a lecture, and tackles it in collaboration with students. Teacher offers various attitudes to solving the problem, takes into account student's suggestions, corrects them and incorporates chosen observations into the process of learning. The lecturer should give students enough time, and oversee that they take an appropriate notes. In the case of a selfwork, tutor must not forget to check the results[319].
A study has been conducted on **how much of the thinking time on average is given to students to respond to a lecturer's question**, Fischer (1997) with a surprising result of **one second**. After that they tend to provide the answer themselves, or ask another question. Rohlikova, Vejvodova (2012) suggest, that **prolonging the thinking time** leads to an increasing willingness of students to participate (more students come with the suggestions), and to producing longer, more creative and more thought over answers.
Vasutova (2002) believes, that every lecture should include a **discussion** (either during or at the end of a lecture). She claims that some teachers are afraid of conducting "large group" discussions, nevertheless states, that an experienced lecturers are able to innitiate a dialogue in an auditorium with more than hundred students by fuelling their enthusiasm and eagerness to ask questions, which the tutor needs to process quickly.

[318] source: ROHLIKOVA, VEJVODOVA (2012)
[319] source: ROHLIKOVA, VEJVODOVA (2012)

Petty (2001) points out that by encouraging a discussion with students, teacher makes clear, that he is interested in what they think, and values their opinion. It is important to pay attention to a reflexion at the end of the lecture, so the students would realize their active participation resp. the value of their contribution.

Activity of students can be also boosted by techniques such us "**Buzz groups**", (when in order to stimulate an attention, the lecturer asks the students to form small groups and challenges them with some tasks, results of which are after a short time discussed with the rest of the audience) or by a **quick poll**[320]. Both of these methods give the lectureer a relatively quick feedback, furthermore the Buzz method gives an opportunity to share their views also to the shy students, and the quick poll presses the "otherwise lazy" students to take part.

Rohlikova, Vejvodova (2012) observe that majority of university lectures contain no significant interraction, which is sometimes caused by the fact, that lectures are not compulsory, and the teacher does not know, how many students are going to attend, therefore cannot plan ahead particular activity. **Decrease in number of attending students** grows especially when the lectures are perceived as being "relatively easy", not demanding, when the peadgogue is less strict, and when the lectures more less copy the study materials.

It is also advisable to **use more effective techniques and methods of teaching during lectures,** as it indicates pedagogical erudition as well as an interest in improving students' learning.

Stech and Vasutova (1999)[321] highlight that lecture is not only a reproduction of facts or thoughts. S**tudents act as a catalyst** for the proces of rediscovery, the lecture gets refined, and can also lead to the teacher's further research activity.

In terms of concentration, the lecture is one of the most demanding methods of learning for students. The teacher cannot hold the attention of all class for the whole lecture for the reason, that the **concentration span** whilst listening to a teacher is only **around 15-20 minutes** for grammar school students or undergraduates (less then 5 minutes for primary school children); and the attention span of particular students furthermore differs slightly. As a consequence, it means, that **any chosen student will experience random cuts-outs from the lecture** (see Fig. 23). Therefore, a **slow down** accompanied by a "question time" or by a short distraction in the form of some demonstration is recommended approximately **every 20 minutes, and a**

[320] in Bohm, Jerman: ***Alternativní metody výuky*** *(Alternative methods of teaching)*, 2010; source: ROHLIKOVA, VEJVODOVA (2012)

[321] in ***Vybrané otázky vysokoškolské pedagogiky*** *(Selected questions from higher education pedagogy)*, Prague, ÚVRŠ PedF UK, 1999; source: ROHLIKOVA, VEJVODOVA (2012)

disguised repetition (in order not to bore the students who listen well) might be appropriate as often as possible[322].

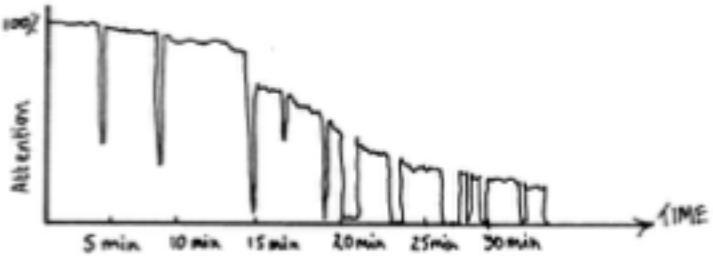

Fig. G1.2.1 Concentration span of a university student. Source: Petty (2004), pg. 128.

When planning the lectures, it is advisable to take into account a typical **distribution of a performance** according to a person's physiological capabilities **over a daytime** as published in Seiwert[323], which peaks between 9-12 a.m., and again between 4-6 p.m. though to approx. value compared to previus one lessen by thirty percent.

It is also important, that **students come prepared for the lectures.** Prof **Pitha**[324] pointed out in one of his speeches[325] that "a **student cannot properly think without certain amount of knowledge**, because he is not able to put a new information into the context or to compare it".

Students need to master the **skill of taking notes** from the lecture, otherwise their unduly concentration on the activity may negatively influence the perception of the lecture's content. Lecturers may tackle this problem by giving out the handouts for the lectures as well as let the students access slide presentations, syllabi etc.[326]

An integral part of nowaday's teaching is a **utilisation of modern technologies**. In relation to a lecture, all participants of teaching process can appreciate the advantages of easier organisational aspects (communication through internet, quick consultation, source of general

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[322] PETTY (2004)

[323] ROHLIKOVA, VEJVODOVA (2012)

[324] Prof PhDr **Petr Piťha** (born 1938): Czech catholic priest, bohemist, linguist and educator (Minister of Education between 1992-1994); author of number of books also in the field of education; received Comenius Unesco Medal for his work

[325] at Pedagogical days of Hradec Kralove Pedagogical faculty in 2008, (***Velká iluze českého školství***, *The Great Illusion of the Czech Education,* critical speech commenting the situation in the Czech Republic's education)

[326] ROHLIKOVA, VEJVODOVA (2012)

(on the contents of subject) or specific (syllabi, coursework assignments) information) as well as a wider range of options for presentation itself (watching online videos, listen to audios, following demonstrations on models, viewing computer simulations, virtual reality...).

Despite undisputable prevailing advantages of incorporating modern technologies into a lecture, there are also some situations a tutor should avoid, such us **turning a lecture into multi-media show** (analogy to Fox's effect[327]) with low to zero educational value as described in **Vasutova** (2002).

When using modern technologies (e.g. projection of a lecture notes instead of now "outdated" writing them on the blackboard), attention should be also paid to give students enough time for taking the notes in case the displayed information is not freely accessible later. On the contrary, sometimes a **simultaneous writing on the blackboard** can be a good way to keep the pace of the lecture, when students do not copy hurriedly all material projected without really paying attention to it, but follow the lecturer's progress and thoughts.

Positive vs. negative effects on learning whilst using "new" technologies has been analysed and summed up in a table by **M. Petterson** (Light, Cox, 2001), reprinted in **Vasutova** (2002). On the situation was looked in an intelectual, practical, personnal and social context. To highlight the most important pros as far as an **intellectual dimension** is concerned, let's name an increase in interactive learning, access to a great range of study materials or being introduced to various attitudes, most significant cons are represented by reduced feedback options or hesitancy in a decising making. From the **practical point of view**, improving computational skills together with the possibility of an active learning can be counted as pros, whilst overly concentration on computer skills at the expense of other skills represents the cons. **Personnal aspects** value positively strengthening the role of a student with the prospects of personal development, whilst the risk of overloading with information, or de-humanisation of the learning process are seen as cons. **Social dimension** praises wider possibilities of cooperation between student and teacher, and between students themselves, but on the other hand the role of a "moderator" of a dialogue is diminished.

On-line courses display both advantages and disadvanteges, and it is up to each particular institution and lecturer if and up to what extent are they going to use them. For the institution,

[327] **Fox's effect**: a charismatic speaker could fool a knowledgeable into believing any old rubbish was in fact meaningful and worthwhile, experiment in 1970;
source: https://learningspy.co.uk/psychology/dr-fox-teaches-us-importance-subject-knowledge/
visited July 2019

it is very cost-effective. From the students' side, it gives a comfort to part time or flexible programmes' students, but there limited to none option to continue with a course if someting is unclear and there is no one to explain that particular matter.

Advantages of a lecture

- suitable for students with **auditory**[328] learning style
- allows the lecturer to **plan** the exact **aims, content, pace, direction and organisation of a lecture** (not fully applicable to lectures, where discussions take place as the tutor is required to deal with student's questions, comments and unanticipated ideas)
- **more comprehensible** if delivered by a lecturer (**compared to textbooks** with more complex composition of sentences)
- possibility to explain more complex or specific technical terms directly at the lecture (some students might struggle during the selfstudy)
- a chance to **stimulate an interest** (e.g. by performing experiments, by adding interesting details, by sharing own experiences...)
- if a video etc. is watched together, lecturer can further comment or explain its content
- **quick, cheap and efficient** way of introducing a large number of students to a certain topic

Disadvantages of a lecture

- **predominantly one way communication**, therefore the lecturer must make an effort to find out if they understand or if someone struggles
- **limited participation of an audience** / their passivity
- **not much effective if students don't come prepared** (difficult to follow up if they do not understand contents of previous lectures - especially markable with technical subjects such as statics)
- considerable amount of unguided study is required
- lecturer needs to have or to learn an effective writing and speaking skills

[328] **auditory learning style**: a person learns through listening
https://www.thoughtco.com/auditory-learning-style-p3-3212038
visited July 2019

Enhancing learning in large classes[329]

can be supported by following recommendations:

- choose **simple words** when lecturing
- give out **hand-outs** with more complex terminology
- eliminate slang and informal expressions
- refer students with difficulties to extra help programmes
- **ask questions, wait for answers**, allow silence (at least 5 sec)
- **show** students **how to perform an important skills needed for the course**
- be aware that not all students ask for advice when they need it, and reach out to them
- try to personalize the course for students
- encourage students to form study groups

Suggestions for more effective lecturing[330]

- **begin** each class with something **familiar**
- **make connections** to ongoing events
- **start and finish** each class with a **summary** of the lecture's main points
- relate the lecture to previous and forthcomming classes
- **check regularly** throughout **if students understand** (ask questions or present a problem, look for nonverbal clues of confusion such us clock watching, loss of eye conatct, talking...)
- do not "read" from the textbook (use a different way to explain the matter), so it can be an alternative resource
- consider using variety of media to make lectures more interesting
- **be aware of "technical" settings**: e.g. the text is large enough to be seen even from the last row of seats, notes cannot be taken in darkened room
- give students enough time to take notes

SEMINAR

"A seminar means a **class or meeting**...An educational *seminar* indicates a small, advanced study, while a meeting labeled as such means an intense exchange of ideas.

The Latin *seminarium* originally referred to a plant nursery, a place of great growth. From this came the German *seminar*, referring to a formal educational group led by a professor.

[329] from CIRTL (Center for the Integration and research, teaching and learning) website, visited August 2019

[330] from CIRTL (Center for the Integration and research, teaching and learning) website

While **university seminars are most frequently small-group studies of a particular issue**, the word is also applied to large lectures and commercial pitches."[331]

The **seminar** acts as an accompaniment to lectures. Students attending the seminar meet with the lecturer or his assisstant in smaller groups (around 10-15 people) in order to deepen and to practice the knowledge they got introduced to during the lectures. Classic seminar teaches students **critical thinking, argumentation, interpretation of the facts, problems solving and cooperation**, and also introduces them to the research work and its methodology (they learn how to use analysis, synthesis, comparation, analogy, generalisation, concretisation, induction, and deduction). The seminar focuses on a discussion, and presentation, as a part of their activities, students can for example conduct a small-scale research or create theoretical models. They also practice a professional communication.[332]

Petty (2001) points out that seminar **should not be in the form of lengthhy general discussion**, and should concentrate on relatively specific topic, which is submitted to a discussion instead. **Rohlikova, Vejvodova** (2012) say that monologue methods (presentation, demonstration), can be used at seminar but only to complement the lecture, not to become a mini-lecture of its own.

There is also a **pro-seminar** in university curriculum - a preparatory course for undergraduates, which is carried in the form of a seminar.

During the seminar, following **teaching methods are used**:

- presentation and demonstration
- discussion
- cooperation and collaboration
- problem solving, research methods
- simulation, inscenation

We will look at the particular methods in detail later on.[333]

In the connection to the topic, **Rohlikova, Vejvodova** (2012) observe initial surprise or even **unwillingness of students to adopt an active attitude** to learning. This experience is described also by **Kotrba, Lacina** (2007)[334]on the example of students' first reactions to introduding an inscenation into the seminar at the Faculty of Business and Economics, Mendel University Brno.

[331] source: https://www.vocabulary.com › dictionary › seminar, visited August 2019

[332] ROHLIKOVA, VEJVODOVA (2012)

[333] see pp. 217-219 for detailed info

[334] in ***Praktické využití aktivizačních metod ve výuce*** *(Practical use of activation methods in education)*, Brno, 2007, Barrister& Principal, source: ROHLIKOVA, VEJVODOVA (2012)

Rohlikova, Vejvodova (2012) propose to pay attention to the quality of a seminar if based predominantly on the presentations of students' papers, and put emphasis onto **avoiding monotonous re-reading** of the long elaborates. **Vasutova** (2002) recommends applying **following strategies for guiding student's work at the seminar**:

- highlight the importance of a proper structure of the paper (must include annotation, keywords, methodology conclusions, resources)
- address that students adopt a professional terminology and express themselves briefly, concisely, clearly, exactly, and to the point
- present suitable examples
- practice presetantion and discussion skills during seminars
- evaluate each paper from different points of view and overall
- encourage students' participation at conferences (initially as observers, later as presenters)
- give feedback (ideally from multiple sources), analyze mistakes, praise the good parts

Seminar PROS

- represents more sophisticated form of learning
- teaches students critical thinking, argumentation, interpretation of the facts, problems solving and cooperation
- introduces students to the research work and its methodology
- focuses on discussion and presentation
- represents the possibility to practice a professional communication

Seminar CONS

- time consuming teaching method
- more preparation time is needed
- students might not be willing to participate
- risk of monotonous re-reading of students' long elaborates
- risk of becoming a mini-lecture of its own

EXERCISE

University exercises can either complement a lecture or form independent study blocks. Compared to the seminar, their content is **more practically orientated** e.g. focus on **applying the theoretical knowledge acquired during lectures**, or on **practicing skills**. The size of the class is usually around 20 students, and is lead by lecturer himself or his assistants. Special type of exercise is a **laboratory work**.

As for statics, exercises are predominantly devoted to learning how to determine the internal forces in a particular type/part of a structure (learning how to create an appropriate static model of a structure, and use the calculation or approximate graphic methods), which is further used for learning to pre-dimension its particular structural members. Students can also work with small-scale models (e.g. observe their behaviour under load) or get introduced to various computational programmes.

During the exercise, following **teaching methods are used**:

- group tuition
- practical skills learning
- cooperation, collaboration
- project work
- problem solving
- simulation, inscenation

OTHER FORMS OF TEACHING

Other forms of teaching are represented by the following activities:

consultations, lectures by experts, excursions, study praxis, internship, selfstudy.

Most of them bring students closer towards the real environment of their future profession, therefore they are of a great importance.[335]

Study praxis takes place outside the school building, predominantly without university lecturer's supervision. Students integrate working teams **in the field of their future profession**, where they have an opportunity to confront theoretical knowledge with the reality of the workplace, to test their prerequisitions for the profesion, to connect himself with a profession or even reveal its pitfalls.[336] Study praxis might take part during or after studies. Some schools require participation even beforehands (e.g. 3 months of manual internship requested by the ABK Stuttgart in Germany). English universities' study programmes offer either a variety incorporating professional praxis or make praxis integral part of the curricula (e.g. two 6-months long periods at the University of Bath in the second terms of the 2nd and the 3rd year),

Internship is more advanced form of the study praxis.

Excursions take part outside the school, and most of the schools include them in their curricula (e.g at ETH Zurich directly organised by the Department of Structural Design). The programme of a particular excursion has a specified **learning goal** and a **direct relation**

[335] For the specific examples concerning particular universities see G1.3 part / Case studies, pp. 237-335

[336] ROHLIKOVA, VEJVODOVA (2012)

towards study plans. Students are often required to produce an output (report, analysis, sketches.) from the excursion.

Lectures by experts provide a connection with a real world, and therefore are of a great educational value.

Consultations are important parts of university studies; Rohlikova, Vejvodova (2012) compiled following suggestions for teachers how to conduct consultations: conduct preferably an active dialogue (50/50 ratio), be prepared, listen to the students, keep an eye contact, take notes, give students enough time to formulate thoughts, show them that you listen - ask specific questions, ask questions to the core.

Selfstudy is a learning activity, during which students gain knowledge by studying on their own, relatively independently from an external assistence. [337], however the self study referred to in various universities study plans is de-facto **self-directed study**, which is for some subjects further individualised.[338] Tutors are behind "symbolic barriers", which students need to overcome on their way to particular learning goal.[339]

Manak, Svec (2003) differenciates 4 levels of studen's activity according to the teacher's influence as well as 4 levels of studen's dependency, which are directly related.

Rogers (1951) [340] believes that the teacher should not organize (giving information, suggesting ways of conduct, constantly check) student's work at any cost, but should let the student take his own responsibility, and provide expert consultations, which respect student's views.

Self Study PROS

- time and place flexibility
- own pace
- choice of the learning tool in accordance with personnal preferences

Self Study CONS

- there is not always a consultant at hand (for correction or additional explanation) if needed
- difficult to stay motivated

E-learning is a specific form of a self-directed study supported by the ICT technologies (great variety of formats). The study process is **individualised**, however the learning system

[337] MANAK, SVEC (2003)
[338] ROHLIKOVA, VEJVODOVA (2012)
[339] in STECH, VASUTOVA (1999); source: ROHLIKOVA, VEJVODOVA (2012)
[340] ROHLIKOVA, VEJVODOVA (2012)

is **didactically thought-out.** Important part of such system is an **instant feedback**. Successful incorporating of e-learning in teaching statics to architectural students is reported in detail for example by Evernden et al.[341] (2013), describing the situation at the university of Bath.

Kveton (2003) distinguishes 3 main types of online learning support.

1. **static use of web**
    - materials of organisational character (schedule of the course (dates, time, topics)
    - course rules (attendancy, evaluation)
    - material supporting the course (lecture slides, syllabi) and coursework (sample homework, web links to related information (e.g. some technical parametres))
2. **dynamic use of web**
    - on-line educational sources
    - on-line self tests
    - on-line portal enabling co-working on a task
    - consulation and discussions (on-line groups)
    - interactive programes
    - various multimedia content
3. **complete on-line course**

Zounek (2006) is also focusing on the e-learning problematics, bringing up into discussion following pros and cons of e-learning:

E-learning PROS

- people do not have to be together to participate at some activity (more cost effective)
- time flexibility
- asynchronous activities (forum, mail) do not require expensive equipment and are more flexible
- sophistical virtual environment allows to create individualised assignments
- learning materials can be reused (e.g. with modified inputs)
- own pace, variable sequence of tasks
- choice of the type of learning tool (audio, visual, text, animation...)
- students can participate on the development of teaching materials (comments, additions...)

[341] EVERNDEN, DARBY, IBELL (2013), see p.276 and p.278 for details

- certain level of anonymity (reduces shyness), students can think-up their written responses
- feedback for tutors (see popularity of particular activities, activity of particular students...)

E-learning CONS

- inititiative cost of equipment
- great variety of formats, risk that students will not have necessary equipment
- risk of the information overload, health issues
- constant internet connection needed for synchronous activities (chat)
- asynchronous activities require higher motivation from students than synchronous activities
- requires self discipline and time organisation skills
- not suitable for practical skills training
- limited or none social contact
- if the course is not planned accordingly, there is a risk of overloading students or tutor (prolonged response time leads to insufficient support to students)

Teaching methods

PRESENTATION

Presentation (the **most common seminar activity**) is the **process of presenting a topic to an audience**[342] either by an individual or by the group. The topic is usually selected by the tutor, who also suggests references. Consultation of the findings before the presentation is given to the class is recommended (Petty).

After the presentation, a **discussion** usually takes place.

"Technical" aspects of the presentations in the form of recommendations are widely available online, and should be looked at by the presentees in order to avoid the most frequent mistakes (e.g. number of thoughts at one slide, height of the writing, size of the table...).

DEMONSTRATION

One of the three meanings for a demonstration, the one used in a learning context: "is **the act of showing someone how to do something, or how something works**"[343].

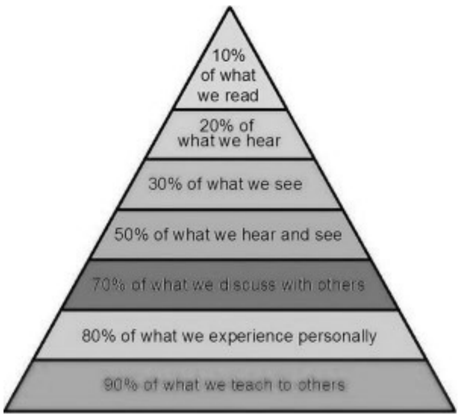
[342] definition: Wiki commons

[343] source: Cambridge Dictionary online, visited August 2019

Despite relatively high abstract thinking ability of university students, **Vejvodova, Rohlikova (2012)** recommend **boosting** their **motivation** by demonstrations, which illustrate the importance of a particular problematics in a real-life.

Demonstration can have many forms such as to bring a real-life subject from a praxis to a class, to watch and analyze various documentaries together, to describe a real-life applications of the taught subject, to incorporate excursions, to organize talks with specialists, or to support all forms of student's praxis[344].

Demonstration as a part of learning process is recommended by e.g. Confucius[345], Commenius[346], Manak, Svec[347] or Petty[348], and supported by **Dale[349]** and his **Cone of experience[350]** (Fig. 24), which depicts the findings that the teaching method is the more effective the closer it is to a real life. Dale followed **Dewey[351]**, according to whom there is a close and necessary relationship between practical experience and effective education, and who prefers that students come into direct contact with the reality they study.



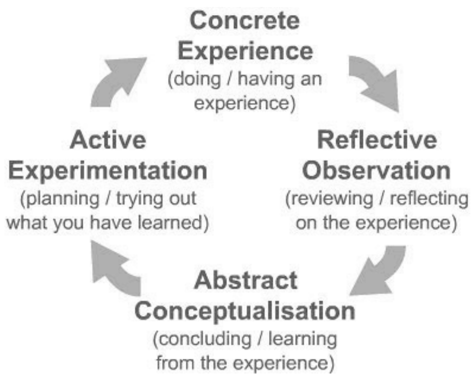


Fig. G1.2.2 Dale's Cone of experience (left)
Fig. G1.2.3 David Kolb's Learning Cycle (1984), (right)

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344 ROHLIKOVA, VEJVODOVA (2012)
345 **Confucius** (551-479 BC): Chinese philosopher and politician; his philosophy emphasises personal and governmental morality, correctness of social relationships, justice and sincerity; source: Wiki commons
346 from easy to more complex (COMENIUS)
347 MANAK, SVEC (2003): distinguish four levels of illustrativness
348 PETTY (2004)
349 **Edgar Dale** (1900-1985): American educator, author of the Cone of Experience; made several contributions to audio and visual instruction, including a methodology for analysing the content of motion pictures; source: Wiki commons
350 created in 1946, source of the picture: http://www.vkmaheshwari.com/WP/?p=2332, downloaded 08/07/2019
351 John Dewey - see fn 289

Dewey put an emphasis on the fact that **we can only gain an experience whilst doing a new activity**, which is in some way **related to our current knowledge**, which is **by such activity further developed**.[352] This idea has inspired **Kolb**[353], who created a model of an experience learning cycle[354] (Fig. 25)- The starting point is represented by the student's direct experience (including perception of the world and himself), which he perceives, observes and thinks-over from various angles of view. The result of this reflexion is represented by conceptualisation of the problem on the abstract level, leading to creating concepts, theories and hypotheses. An active experimentation follows, bringing the new experience, submitted to the new reflexion etc. The process of creating knowledge us therefore not linear, but cyclic.

Demonstration PROS

- improves understanding
- leads to a more permanent knowledge (more senses involved)
- some things are better seen in praxis then explained by words
- helps in developing spirit of enquiry

Demonstration CONS

- more demanding preparation (considerable time to premeditate the actual process of demonstration and to make it)
- not every principle can be demonstarted

Despite predominantly positive assessments of incorporating demonstrations into lectures (conferences papers), I have come across an interesting opinion stating different experience. E. **Mazur**[355] from Harvard University of learning says that in relation to the physics teaching:[356] "**while in-class demonstrations engage students, they may not be effective because students do not always learn what is intended**".
P.M. **Kraus** from the University of Washington, does not dissmiss demonstrations as such, but has made an interesting observation whilst working on her doctoral thesis at the

[352] ROHLIKOVA, VEJVODOVA (2012)
[353] **David Allen Kolb** (born 1939): American educational theorist whose interests and publication focus on experimental learning, the individual and social change, career development and executive and professional education; source: Wiki commons
[354] source of the picture: https://www.simplypsychology.org/learning-kolb.html, visited August 2019
[355] **Eric Mazur** (born 1954): physicist and educator at Harvard University; also entrepreneur in technology start-ups for the educational and technology markets; source: Wiki commons
[356] ***The Pros and Cons of Demonstrations in the Physics Classroom*** (2017);
source: blog.theexpertta.com, visited August 2019

University of Washington [357] (devoted to the promoting an active learning through demonstrations), claiming that **many lecture demonstrations do not help students better understand** targeted concepts **because of the way of they are predominantly presented**. She further specialised on the student learning in a lecture-based courses and came to the conclusion that the **guided inquiry approach (effectively used in the small-group tutorials) would be more appropiriate** and could be adapted to use in large lecture courses.

DISCUSSION

It is a good method, when students **practice cognitive skills** such as an evaluation, and which lead to forming their opinions. It can be **left open, but preferrably structured** e.g. by some controversial questions, which can bring the strong answers. According to Rohlikova, Vejvodova (2012), an **appropriate question** should be factually and gramatically correct, specific (not too general), should activate thinking, should be asked at the right time (the right place at the sequence of questions), and should act as a way to express an individual attitude. A proper question can even induce a **cognitive conflict** (to unbalance a person). Fischer (1997) thinks that a **good question** is the source of unrest in the mind, initiates thinking and looking for the answer. In his opinion, good questions are not easy to answer, and request a thoughtful, flexible answer, but they are productive. Fischer also states, that it depends on the type of question, whether a higher-orderor a lower-order thinking[358] is going to be invoked, and finds higher-order questions as more appropriate for university courses.

Higher-order questions lead to thinking (either evoke interest and curiosity and therefore focus attention, or ask for opinions, feeling and experiences, therefore ignite discussion). Lower-order questions verify the exploitation of knowledge (they either target finding the level of understanding (including monitoring eventual difficulties), or check the process of learning, and therefore lead to further learning). Lower-order thinking is represented by questions connected to knowledge (What? Who? When? Where? How?), understanding (What means...? How can you explain...?), or application (What are some other examples?), whilst questions connected with higher-order thinking are those of analysis (? typical features of something), synthesis (How can we contribute to...?), assessment (What do you think of...?).

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[357] Pamela Ann Kraus: ***Promoting active learning in lecture-based courses: Demonstrations, tutorials, and interactive tutorial lectures***, PhD. thesis, University of Washington, December 1997

[358] **higher-order-thinking** is a concept of education reform based onlearning taxonomies (such as Bloom's taxonomy); the idea is that some types of learning require more cognitive processing than others, but also have more generalised benefits; high-order thinking involves the learning of complex judgmental skills such as critical thinking and problem solving; **lower-order thinking** is the foundation of skills (remembering, understanding and applying) required to move into higher-order thinking; source: Wiki commons

An example, when the discussion can be used, is, when the tutor wants the students to **explore the different aspects of a particular topic**. Students (or groups of students) can read various materials, form their opinion, and this opinion later defend during the discussion. Giving out the **handouts** contributes positively towards the flow of the discussion.

It is **not supposed to be competitive, but exploratory**, and in the contrast to a debate (which is competitive), participants should feel free to **make hypotheses** and to **change their views**. If everyone is in agreement, the tutor can express the opposite opinion (regardless to his real thoughts) in order to provoke some further comments, or move on once the consensus is established, and the particular point is exhausted. Tutor should make clear that he values each opinion, and he should **make sure that everyone contributes**. Manak, Svec (2003) highlight the importance of conducting not only teacher-student "ping-pong" interraction, but also a mutual interaction between students.

Discussion leader (usually the tutor) can include or exclude himself from the discussion, but he should always **summ-up the main points** and oversee a note taking in order not to forget them. Discussions that take longer then 30 minutes are of questionable value for the same reason.[359]

Students can even take part in the **mutual assessment** (e.g. a structured questionnaire can be given out to fill)[360].

Discussion PROS

- puts more emphasis on learning than teaching
- encourages participation, democratic thinking
- enhances reflective thinking
- helps improve self-expression, articulate ideas
- nurtures spirit of tolerance
- students learn to evaluate and respond to their classmates opinion
- interactive
- active learning- they learn more
- moving up in blooms taxonomy[361] (from memorisation to application)

[359] PETTY (2004)

[360] PETTY (2004)

[361] **Blooms taxonomy** is a set of three hierarchical models (cognitive, affective and sensory) used to classify educational learning objectives into levels of complexity and specificity; the cognitive domain list has been the primary focus of most traditional education and is frequently used to structure learning objectives, assessments

Discussion CONS

- some students will dominate, insecure student may have difficult time to speak up
- note taking is more difficult
- harder for non-auditory learners to absorb
- can cause conflict in the classroom, controversial
- easy to get side-tracked, get out of hand
- unprepared students have nothing to say
- students may ask question the teacher is unprepared/ doesn't know the answer
- students may think the teacher is neglecting his responsibilities and makes students do most work
- it is more difficult for teacher (skilfully guiding discussion is harder then merely stating the facts)

COOPERATIVE LEARNING

Group learning is closely connected with the term cooperative learning. When working together, Vasutova (2002) further distinguishes between a **cooperation** (students split tasks) and a **collaboration** (students work on everything together), however both methods are ordinarily labelled as cooperative learning in literature on general and often used as synonyms. The results of an individual are promoted by the group work and vice versa. A special type of group work is a **work in pairs**.

According to Kasikova (2010), in order **to ensure a desired progress in learning** (whilst a cooperation), following 5 elements must be in harmony: **positive interdependencies** between the team members, **face to face interaction**, **idividual responsibility for the group results**, development of **social skills and a reflexion**[362]. The **positive links** between students can be supported e.g. **through a goal** (everyone in the group shoul understand..., every team member must suggest 5 ideas...), **a source** (the group receives only 1 working sheet), **an identity** (each group chose their logo, name, motto...), **a space** (your group stays at one table and everyone should be able to read instructions from a worksheet), **the sequences** (particular steps of a project are given to particular members of a group), **a reward** (each member of a group receive extra point in test under condition that everyone in group can explain...), **working roles** (roles might be pre-defined as: leader, speaker...), **a stimulation** (one

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and activities; the first volume of taxonomy (Handbook I: Cognitive] was published in 1956, the second (Handbook II: Affective) in 1964; revised version was created in 2001; source: Wiki commons

[362] **Reflexion** (a look back at an activity) is a process that helps to exploit and process the experience gained during the activity
source: wiki.rvp.cz, citing Reitmayerova, E.: ***Cílená zpětná vazba: metody pro vedoucí skupin a učitele*** *(Targeted feedback: methods for group leaders and teachers),* Prague, Portal, 2015

particular group gets the task to defend a different opinion to the rest of the class, the members of this group should support each other in a discussion), **an alteration** (group members fulfill the assigned role in a pretend-situation) , **an identity, and via an external influence** (the first group submitting correct result is going to be awarded).

PROJECT LEARNING

The concept of a project learning dates to the turn of the 19th and 20th century, and is attributed to John Dewey, an American pragmatic pedagogist [363]. Dewey did not use the term of "project learning", but created a theoretical knowledge on which is it based. [364]

Project learning is represented by a **complex dealing with either theoretical or the real-life problems**, which is based on student's active work; Skalkova (2002)

In the opinion of Rohlikova, Vejvodova (2012), students's projects should ideally be described by the following words: well chosen and **clearly specified, with the goals possible to meet, interesting or even unusual, diverse, requiring an active participation, praxis-related**.

Petty states on the project work, that "there are not so many methods like project that allow the tutor to develop such a broad range of skills, and simultaneously give him even bigger chance to waste the time if the organisation is bad

There are **4 different types of a project according to Kilpatrick**[365] [366]:

1. projects following thoughts/plan (e.g. a boat building)
2. projects focusing on finding a particular experience (e.g. an aesthetic experience through a music listening)

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[363] John Dewey, representative of American pragmatic pedagogy, see fn 289

The pragmatist pedagogy (or instrumentalist pedagogy): pedagogical theory from the last decade of the 19th century; based on a pragmatic philosophy, it saw a large spread in the USA; J. Dewey considered the ideas and theories as instruments of action, the only criteria of truth being the success of the individual activity

source: Epurescu,O.: ***Pragmatist pedagogy and a single name: John Dewey***, in Journal of educational sciences and psychology, vol VI, No.1B(2016), 92-95

[364] source: Slejskova, L, Gosova, V., rvp metodicky portal, see also Fig. G1.2.2 (Dale's Cone of Learning), p. 224

[365] in Cipro, M.: ***Galerie svetovych pedagogu*** *(The gallery of the world pedagogists]*, Prague, 2002; source: ROHLIKOVA, VEJVODOVA (2012)

[366] **William Heard Kilpatrick** (1871-1965): American pedagogue and pupil, colleague and successor of john Dewey; major figure in the progressive education movement in the early 20th century; source: Wiki commons

3. intelectually orientated projects
4. projects leading to an adoption of certain principles/skills
University projects are typical for **combining** all above categories, being simultaneously predominantly of a **research character**.

Project learning PROS:

- combines using of the knowledge from different areas
- helps to see an interconnections between different knowledge areas and connection to a real life
- allows an individualisation of the assignment
- provides a motivation, activizes students
- can be done either individually or in groups

Project learning CONS:

- time consuming for pedagogue (individual or small group consultations)
- problematic if students do not have an appropriate level of knowledge to start with
- if consultations are not compulsory/set up regularly, some students might not work diligently which results in a poor overall quality of work

A useful tool for assessing the **strengths**, the **weaknesses**, the **opportunities** and the **threats** within the scope of project learning is the **SWOT Analysis** with following four cathegories:

S STRENGTHS
hepful to achieving the objective
internal origin (attributes of the organisation)

W WEAKNESSES
harmful to achieving the objective
internal origin (attributes of the organisation)
O OPPORTUNITIES
helpful to achieving the objective
external origin (attributes of the environment)

T THREATS
harmful to achieving the objective
external origin (attributes of the environment)

PROBLEM LEARNING (PBL)

According to Rohlikova, Vejvodova (2012) **universities prepare** its graduates either for a **research work or to deal with various challenges at work**, therefore heuristic methods should belong to fundamental teaching methods's repertoire of university educator.

Manak, Svec (2003) point out, that the most difficult part is to define the problem and describe the situation as difficult, unclear and new.

Skalkova (2002), with references to psychology, highlights the fact, that **knowledge and skills gained during a problem solving** are **more permanent** to those learned by heart from a textbook or by listening to a lecture.

Rohlikova, Vejvodova (2012) distinguish 3 main problem solving strategies:

1. **algorithmic procedures** give an exact sequence of steps, that must be aboden in order to get the result
2. **heuristic (research/discovery) strategies** support an intensive logical analysis and an individual approach towards the problem
3. **intuitive process** is more spontaneous, nevertheless might lead to a solution;

Solving problems by and indirect and creative approach (viewing the problem in a new and unusual way) is referred to as a **lateral thinking**[367], for which folowing attributes are typical: being ready and able to change steady patterns, ask provocative questions, use humour, and not to worry return a step back.

Heuristic processes are further divided into 4 stages by Skalkova and Polya[368]

1.**grasping the problem** (identifying the circumstances)

2.**conceiving a plan** (the most demanding part; synthesis of inputs which leads to the solution)

3.**verification of each step** (might even lead to return to previous steps which need improving)

4.**systematisation of methods** (might be used in future)

For a successful application of heuristic methods, following aspects should run accordingly:

1.**activity** (students must actively look and check various possibilities)

[367] **Lateral thinking** is a manner of solving problems using an indirect and creative approach via reasoning that is not immediately obvious. It involves ideas that may not be obtainable using only traditional step-by-step logic. The term was promulgated in 1967 by Edward de Bono; source: Wiki commons

[368] source: ROHLIKOVA, VEJVODOVA (2012)

2.**motivation** (students should feel personnal involvement)
3.**continuity** of particular steps (students learn how to adapt their thoughts in accordance with a heuristic method)

Vasutova (2002) recommends following types of problem learning to be practiced at universities:
1. a task with an **incompleted information** (more complex, teaches student to search for information)
2. a task with an **excessive information** supplied (teaches student sort information, distinguish what is important and what is not, make decisions...)
3. **unspecified goal** of the assignment (student should discover the purpose himself)
4. case studies where **consideration of all pros and cons of particular varieties** are needed to be **taken into account**
5. **evocation of ideas** (e.g. brainstorming, which leads to an immediate and often creative thoughts)
6. **complex problem tasks** (students learn to identify partial tasks, set priorities, search for and sort information...)

Examples of heuristic methods:
1.**The black box**:
students are given the start information and results only, must find out, what happened in between
2. **confrontation method**
teacher introduces at least 2 correct methods, which contradict each other
students make analysis, form conclusion
3. **method of paradoxes**
Students justify a contradiction between theoretical statements, laws, theory and common phenomenon in praxis or a statement that contradicts theory

Examples of creative methods **(Mužík,** 1998**, Belz, Siegrist**, 2001)[369]
1. **Brainwriting 6-3-5**
Each out of 6 participants writes within 5 minutes 3 possible sollutions of the problem. After 5 minutes hands out his writing to his neighbour, who either further developes some ideas or bring some new ideas. The notes gradually make a full circle.

[369] source: ROHLIKOVA, VEJVODOVA (2012)

Advantages: writing form prevents any disturbances (conflicts, stress, endless discussion), dominant members cannot control the group, shy members might prefer certain level of anonymity that bring the written form, might appreciate silence to concentrate on thoughts.

2. **Brainpool**

an analogy of brainstorming, papers do not circle round, but are put into the middle with th eoption of exchanging paper at will

3.**HOBO method**

designed by Miroslav Borak, type of study based on preparation problems for brainstorming

4. **collective notebook** CNB

there is an introductory session on the problem, and then every member of a group contributes on the topic (thoughts, solutions) to his own notebook for a longer time (1 to several months), evaluation at the end of a set time, suitable especially for long-distance study

5. **morphology box**

some complex problems can be solved only if split into follow-up partial problems, which are solved gradually

PBL PROS

- promotes deep learning
- developes retention of knowledge in the long term
- introduces open-ended questions
- improves teamwork and interpersonnal skills
- an opportunity to apply skills into the real world
- emphasises higher order of thinking, de-emphasises memorisation
- learning is relevant to the real world
- method is student centered
- increases motivation

PBL CONS

- requires a lot of time and effort to implement
- poor performance of students in theoretical tests

Devoting too much time to PBL activities can create issues when students appear for standardised tests.

This is because they may not have the right breadth of knowledge to achieve high scores in such examination.

- integration of mutiple disciplines
- varying degree of applicability and relevancy
- objective evaluation may be difficult

INVESTIGATIVE and RESEARCH METHODS

<u>CASE STUDY</u> is a **factual description** (relevant information) of a **real situation** at some industry, company etc.

There are **several options how to conduct the study**:

1. the study contains description of a situation, including problems and solutions -students only comment
2. the study contains description of a situation and problems - students suggest a solution, which they support by arguments
3. the study contains description of a situation only - students have to find and describe the problem, come up with a solution, which they further support with arguments
4. students are introduced to a certain environment, which they describe, find problems, propose solution, provide argumentation

Case studies are generally thought to be of a great educational value.

<u>ACTION RESEARCH</u>

The main purpose of an action research is to **create a simple, easy to conduct process, which can be repeated in the form of iterative process of learning, evaluation and improvement.** Overall it leads to general improvement.

AR cycle:

1. identification of a problem
2. collection of data
3. analysis, interpretation
4. developing a plan
5. implementing a plan
6. evaluation (actions taken vs. results)
7. (1.) identification of a new problem

repeat the process[370]

Stech and Vasutova claim, that since the end of 70s, action research is promoted as a teaching method suitable for application at university. It **leads to mastering the skills of problem forming, data collection, evaluation and interpretation**.

<u>PROBLEM SOLVING THROUGH AN EXPERIMENT</u>

is recommended by Rohlikova, Vejvodova (2012) not only for its cognitive values, but also for the reason, that it promotes scientific research, data processing and their critical appraisal. Manak, Svec (2003) see the experiment as a research **approach towards reality**.

[370] source: https://www.edglossary.org/action-research/, visited August 2019

SIMULATION, SITUATION, and INSCENATION MEHODS

Following methods are briefly introduced in order to present the full scale of teaching methods available; however we **do not see any significant benefits when applied into statics lecturing.**

Manak (2003) distinguishes 3 types of didactic "plays"

1. an interactive plays
2. a simulation plays
3. a scenic plays

The **simulation methods** are based on playing roles in model situations with pre-defined rules. Vasutova (2002) praises their sutability for gaining both skills and knowledge.
Skalkova (2007) points out that compared to a real-life situations, these model situations are not so confrontational, and therefore good for practice.
Some types of activities are more approprite for a certain environment e.g. fictional companies fair for schools of economics, micro-teaching for schools of pedagogy. For all university students are beneficial **students' conferences**, which have found an important place in curricullum.

Students' conferences PROS:

- students can improve their presenattion skills
- s. learn to defend their view
- s. get feedback from a wider audience, mostly working in the same or closely related field of interest

Students' conferences CONS:

- presented only to a closed group of participant (from the same background, which might lead to limited points of view)
- When applied to teaching statics, student conferences might be more benfitial between participants with the same specialisation but from different universities. This would be challenging to organize, and if running as a videoconference, lack of personnal connection might be disadvantage. Cannot see the sense of it for comparing notes on ordinary lecture, more apropriate e.g. for some project student work throughout the year and then compare solutions.

The main focus of **situational methods** of learning is to deal with a real case. According to Manak, we can further divide it into 5 phases: 1. presenattion of a case 2. getting information 3.working on the case 4. analysis of the case, discussion 5. evaluation, general conclusions.

Inscenation methods can contribute towards the social skills learning, and are seen as appropriate to use when the subject of learning concerns people's feelings, motives and mutual relations .Vejvodova, Rohlikova (2012).

Higher education didactics conclusion is located in the main part of the study.[371]

[371] see p.34

G APPENDICES

G1 SUPPORTING ANALYTICAL PART

G1.3 CASE STUDIES

This chapter of the study focuses on **how SE is taught at selected universities** resp. their faculties of architecture.

As already mentioned, the research analyzes how important is SE within the architectural curricula of English and German speaking European universities[372] compared to CTU[373] in Prague, Czech Republic, however, for its leading position on the world's educational ladders for architectural studies[374], and because of a successfull adoption of its attitude to SE lecturing to architects[375] at several other universities[376], an extra sub-chapter is devoted to MIT[377], Boston, Cambridge, USA.

For the purposes of this research, we have had a closer look at how SE is taught to future architects at the following academic sites:
European universities lecturing in English language (in alphabetical order): UCL London, University of Bath, University of Cambridge, University of Edinburgh, University of Manchester.
European universities lecturing in German language (in alphabetical order): ABK Stuttgart, ETH Zurich[378], HCU Hamburg, RWTH Aachen, TU Munich, UDK Berlin.

Selection of universities has been done predominantly on the basis of their academical performances (repetitive top positions within various reputable rankings[379]), however some of the universities from our sample were included on a basis of displaying some interesting characteristics we would like to point out (e.g. an interesting activity within the curricula, interesting "insider" view or comment etc.).

The Case studies part was further extended by **several specific cases from all over the world** (mostly from the USA, but also from Russia, Turkey, China, Canada...) reporting an interesting projects/attitudes in architectural structural teaching **as described in conference papers**.

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[372] see the analytical-synthetic part of the research, pp.44-86
[373] Czech Technical university; author's affility
[374] e.g. QS World University Rankings (number one in 2015-2019), Times Higher Education Rankings (positions 4-6 in years 2015-2018)
[375] teaching structural principles with the help of graphic statics
[376] textbook on SE "Form and Force" by Allen and Zalewski is used for SE lectures at ETH Zurich, Switzerland, at the University of Cambridge, England and some German universities (e.g. RWTH Aachen)
[377] Massachusetts Institute of Technology
[378] offers also some lessons in English
[379] universities rankings see p.29

MIT BOSTON, CAMBRIDGE, MASSACHUSETTS, USA

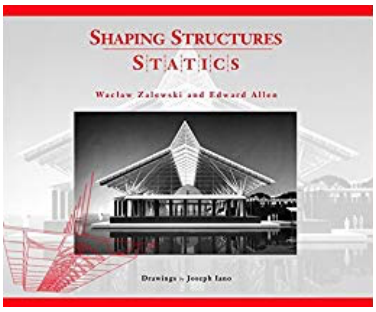
Massachusetts Institute of Technology's School of Architecture and Planning [380] comprises of five departments, one of which is School of Architecture and Planning. As already stated, it has been holding the top positions at various independent rankings[381] (based upon academic reputation, employer reputation and research impact) for several consecutive years.

Bachelor architectural programme at MIT lasts 4 years (8 terms, each of which has got 14 weeks of net teaching time). The number of students in an undergraduate yeargroup is around 40[382]. SE subjects (**Structural Design I+II**) belong to the compulsory section of curricula, and take part during year 2, resp. year 3 of architectural studies. There are two 90-minutes lectures and one laboratory session lasting 120 minutes of a guided work plus another 180 minutes of a self-work per a calendar week. Teaching is provided by a team of five academics: 1 professor (lectures only), 2 associate professors (lectures or labs) and 2 research assistants or Master students (labs only). There is also a 2-week workshop at the end of each term[383].

Teaching SE at MIT is based on Graphic Statics[384] principles.
The original concept **textbook** from 1998 - ***Shaping Structures: Statics*** (Fig.G1.1.1) by authors **Edward Allen**[385] and **Waclaw Zalewski**[386], both longtime teachers of structures at major American universities, was suceeded by their later work ***Form and Forces: Designing Efficient, Expressive Structures*** in 2009 (Fig.G1.1.2), which is used for the course.
Both books are in the form of an easy to understand visually rich step-by step guide, which combines numerical and graphical methods with the emphasis on graphic approach, analysis of the forces and on explaining fundamental statics principles. The main aim is to lead the designer to devise the most optimal shape and form of a particular structure, whilst taking into account different material options. A great variety of structures is analysed (e.g. suspended structures, trusses, funicular structures, shells and membranes, beams, columns, frames, load-bearing walls or arches to name the main representatives. It is intended for both architectural

[380] founded in 1868, the first department of Architecture in the USA; source: MIT's website
[381] see p.29
[382] 47 students in 2018/2019; source: MIT's website
[383] source: POSPISIL (2017)
[384] see pp.77-78
[385] **Edward Allen see fn 259**
[386] **Waclaw Zalewski see fn 259**

students and practicing architects, and contains examples of structures by significant designers such as Gustave Eiffel[387], Robert Maillart[388] or Pier Luigi Nervi[389].



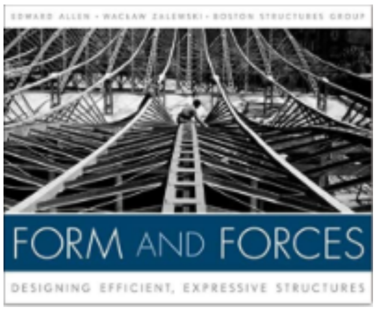


Fig. G1.1.1 ***Shaping Structures Statics*** textbook, ALLEN,W., ZALEWSKI, W.,1998 (left)
Fig. G1.1.2 ***Form and Forces*** textbook, ALLEN,W., ZALEWSKI, W., 2009 (right)

The successors of promoting graphostatics methods of teaching at MIT are Co-Directors of **Structural Design Lab**[390] at MIT: **Professor John Ochsendorf** [391] and **Associate Professor Caitlin Mueller**[392].

[387] **Alexandre Gustave Eiffel** (1832-1923): a French **civil engineer**, a graduate of École Centrale Paris; made his name building various **bridges for the French railway network** (e.g. Garabit viaduct); best known for **Eiffel Tower** built for the 1889 Universal Exposition in Paris and his contribution to building the **Statue of Liberty** in New York; after his retirement from engineering, Eiffel focused on research into meteorology and aerodynamics, making significant contributions in both fields. **Source**: Wiki commons

[388] **Robert Maillart** (1872-1940): a Swiss **civil engineer**; **revolutionised the use of structural reinforced concrete** with such designs as the three-hinged arch and the deck-stiffened arch for bridges, and the beamless floor slab and mushroom ceiling for industrial buildings; his **Salginatobel** (1929–1930) and **Schwandbach** (1933) bridges changed the aesthetics and engineering of bridge construction dramatically and influenced decades of architects and engineers after him**. Source:** Wiki commons

[389] **Pier Luigi Nervi see fn 235**

[390] **Structural Design Lab at MIT** is an
research group focused on conceptual structural design.; co-directed by Professor John Ochsendorf and Professor Caitlin Mueller, the group includes undergraduate and graduate students pursuing degrees in Civil Engineering and Architecture; research interests include form-finding, funicular structures, equilibrium methods, structural optimisation, digital fabrication, and interactive design processes. **Source**: mit.edu website , visited Jan 2019

[391] **John Ochsendorf**: **professor** at the Department of Architecture and the Department of Civil and Environmental Engineering at **MIT, Boston**, USA; **structural engineer** with multi-disciplinary research interests including structural design, masonry mechanics, engineering history, and sustainability; trained in structural engineering at Cornell, Princeton, and the University of Cambridge; conducts research on the assessment of existing structures and the design of new structures; in addition to his academic work, he is a founding partner at the structural engineering consultancy Ochsendorf DeJong & Block, LLC. **Source**: mit.edu website, visited Jan 2019

[392] **Caitlin Mueller: associate professor** at the Department of Architecture at MIT**, Boston,** USA; researcher, designer, and educator working at the interface of architecture and structural engineering; **leads the Digital**

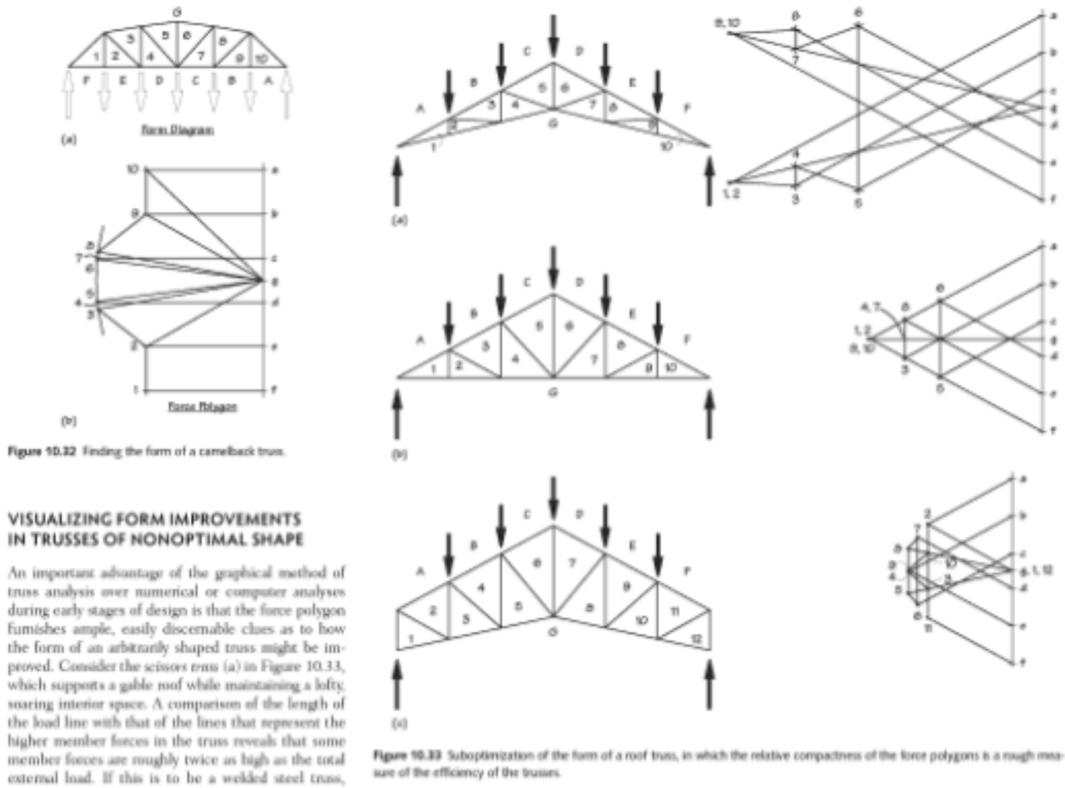


Fig. G1.1.3 Example from the ***Form and Forces*** textbook: form improvement in trusses

The course is accompanied and supported by the graphic statics[393] based **Active Statics Website[394]** (Fig. G1.1.3), which is a set of eight interactive demonstrations that allow its user to experiment with the interconnection between forces and a structural form. As described on the website, the force polygon[395] is constructed automatically, and then adjusted directly and continuously as changes in the form or loading of the structure are made. The magnitudes of member forces are represented by the lengths of the line segments in the force polygon, the numerical values are presented not only by the thickness of the members themselves, but shown in an accompanying table as well. Furthermore, the types of forces are clearly

Structures research group at MIT in addition to **co-directing the Structural Design Lab**; focuses on developing new computational methods and tools for synthesizing architectural and structural intentions in early-stage design; also works in the field of digital fabrication, with a focus on linking high structural performance with new methods of architectural making; furthermore conducts research on the nature of collaboration between architects and engineers from a historical perspective; educated at MIT and Stanford; holds degrees in architecture, structural engineering, and computation. **Source:** mit.edu website, visited Jan 2019

[393] the external forces on each structure are plotted to a scale of lenght to force an a load line. Working from the load line, the forces in the members of the structure are determined by scaling the lengths of lines constructed parallel to the members. The diagram of forces that results from this process is called the force polygon.

[394] originally developed by **Simon Greenwold** (former student) as a graphic statics based tool for presenting his final undergraduate project. This he subsequently completely reworked, expanded and enhanced the demos whilst working closely with W.Zalewski and E. Allen in M.I.T.'s Media Lab during his graduate years

distinguished by a pre-set color-codes: blue color represents tension, red color means compression, and yellow colour symbolizes a zero force. External loads are black, the reactions are green.

Fig. G1.1.4 Introductory page of ***Active Statics*** website

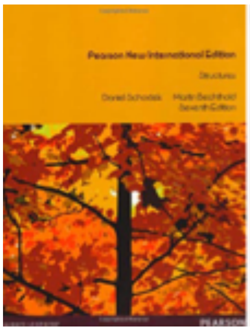
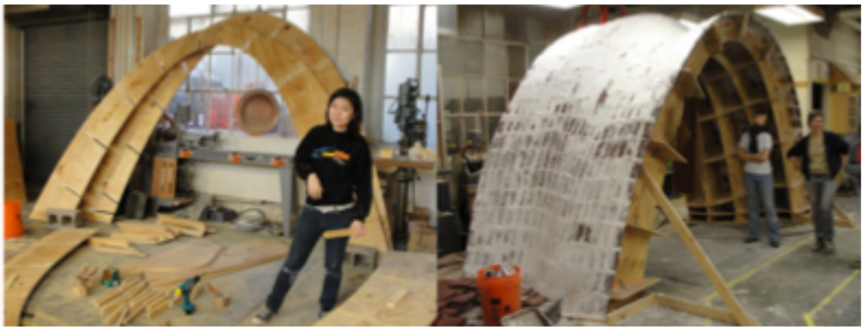
 

Fig.G1.1.5 ***Structures*** textbook, SCHODEK, B., BECHTHOLD, M., 2013
Fig.G1.1.6 MIT Masonry Research Group, June 2009 - January 2010[396]

Another book supplementing the course is **Daniel Schodek's**[397] and **Martin Bechthold's**[398] book called ***Structures*** (Fig.G1.1.5), which covers all the major topics of structural analysis and design with the focus on how the structures really work.

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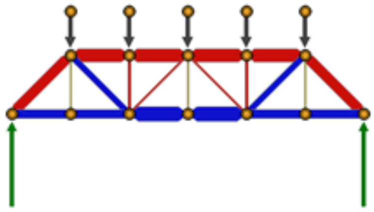
[396] https://vaulting.wordpress.com/page/3/, visited Jan 2019

[397] **Daniel L. Schodek** (1941-2013): a leading figure in architectural technology, an **emeritus faculty member at Harvard University Graduate School of Design**,; promoted a broad vision of architectural design and technology ranging from computer-aided design and manufacturing to smart materials and infrastructure sustainability; author of numerous books and articles, including two books published by MIT Press: *Landmarks in American Civil Engineering* (1987) and *Structures in Sculpture*(1993); his first textbook, *Structures* (Prentice-Hall), now in its seventh edition, is a standard text in the field; **co-designed** (along with Paul Stevenson Oles) **the bridge at West Dover, Vermont** that won the Vermont Bridge Competition in 1989 and the New England AIA award in 1996. **Source:** MIT Press website, visited Jan 2019

[398] **Martin Bechthold**: **director of the Graduate School of Design's Technology Platform at Harvard University**, and Associate Faculty at the Wyss Institute for Biologically Inspired Engineering; teaches courses in design robotics and material systems, building structures, as well as life cycle design; received a Diplom-Ingenieur degree in architecture from the RWTH Aachen, Germany, and a Doctor of Design Degree from the GSD at Harvard University; registered architect in Germany, **practiced in London, Paris, and Hamburg.** (Skidmore, Owings & Merrill, Santiago Calatrava and von Gerkan, Marg & Partner); his research broadly looks at material and fabrication technology as a catalyst of innovation for design practice; in 2010 founded the GSD's Design Robotics Group and recently merged it into the **Material Processes and Systems (MaPS) Group**, a collaboration



Demo #2: Six-Panel Truss

The Screen The **Form Diagram** shows a six-panel truss with its **Force Polygon** to the right and a numerical tabulation of member forces below.

You may move any node that is marked with a yellow circle. All the other parts of the screen will change instantaneously to reflect the consequences of each move–the reactions are recalculated, the force polygon is modified, and the numerical values of member forces change. The thicknesses of the truss members will also change.

Notice the color-coding: Loads are gray, reactions are green. Red is compression, blue is tension, and yellow is zero-force. Members and numbers change color as members change from compression to tension to zero force.

Exercise Two

Truss Depth

Toggles On: Keep Verticals Vertical, Keep Top Chord Level, Keep Uniform Panel Spacings

A. In what region(s) of the truss are the top and bottom chords most highly loaded? In what region(s) are the diagonals most highly loaded?

B. Click on the leftmost node of the top chord. You'll find that you can move the entire top chord up and down with it.

Move the top chord up slowly, and watch what happens to member forces.

Move it down slowly, and watch what happens to member forces as the top chord approaches the bottom chord. Pay particular attention to the Force Polygon as you do this.

What is the general relationship between truss depth and member forces? What proportion of depth to span seems most reasonable to you?

Toggle Off: Keep Top Chord Level

C. Click on the middle node of the top chord. Move it down toward the bottom chord. Watch the Force Polygon to see what happens as this node approaches the bottom chord.

Fig. G1.1.7 Example from ***Active Statics*** website - interactive exercise[399]

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of faculty, research associates, and students that pursues sponsored and other research projects; co-author of *Structures* and *Computer-Aided Design and Manufacturing*, author of *Innovative Surface Structures*. His latest book is *Ceramic Material Systems*. Source:gsd.harvard.edu website, visited Jan 2019

[399] retrieved in Jan 2019 from https://acg.media.mit.edu/people/simong/statics/data/index.html

ETH ZURICH, SWITZERLAND

According to various independent rankings,[400] **Swiss Federal Institute of Technology in Zurich**[401] regularly takes top positions amongst the first ten world universities as far as architectural studies are concerned.

Its **Bachelor degree programme in Architecture**[402] comprises of 180 ECTS[403] credits and regularly takes three years[404]. Bachelor studies begin in German language, and some courses may be taught in English later on (in the second and in the third year). Subjects are divided into three areas, of which architectural design and construction is the faculty's main focus, therefore those subjects cover a substantial share of curricula.[405] The other areas are represented by scientific and technical disciplines in the second part, resp. mathematics, humanities and social sciences in the third section. Six-months long compulsory work experience in the field of architecture is also needed in order to obtain the degree. The number of students in a yeargroup is approximately 250.[406]

The **Master's degree programme in Architecture** at ETH Zurich lasts regularly additional two years, in which students gain 120 credits. The main purpose of extended architectural studies is to broaden previously acquired skills, focus in-depth on one's field of interest (greater proportion of elective courses in curricula), and to put emphasis on increasing independence and on individual approach to work together with learning how to deal with larger-scale architectural assignments. Ten weeks of curricula is reserved for completing the Master's thesis; successful graduate must also fulfill an **external work experience** in the architectural field lasting at least six months.

Let's have a closer look at a representation of SE subjects in curricula now. In the first year of their studies, students get acquainted with structural principles within the subject called **Structural Design I+II** (awarded 2 out of 30 ECTS credits in each term), and also get an introductory project "block" containing the lectures and exercises on the building constructions. The "block" is called **Design and Construction I+II**, it is taught by Andrea

[400] e.g. Times Higher Education 2018 (5th place), QS World University Rankings 2018 (4th place)
[401] founded in 1855
[402] https://arch.ethz.ch/en/studium/studienangebot/bachelor-architektur.html, visited June 2019
[403] **European Credit Transfer System**; for successfully completed studies, ECTS credits are awarded. One academic year corresponds to 60 ECTS credits that are normally equivalent to 1500–1800 hours of total workload, irrespective of standard or qualification type. ECTS credits are used to facilitate transfer and progression throughout the Union.
[404] maximum permitted duration of studies is 5 years
[405] see POSPISIL, VAVRUSKOVA(2013) and dtto (2014)
[406] source: POSPISIL (2017)

Deplazes[407] and his team, and is awarded 8 ECTS in each semester. Four hours of lectures each week are split evenly between the Construction and the Design, and are further accompanied by 2 hours of exercises per week. For the actual project, there are 10 hours reserved in the curriculum.

As far as the organisation of the lectures is concerned, there is a total amount of 14 weeks at disposition per term, 12 of which is equally divided between lectures (the first week and then fortnightly) and excercises (the second week and then fortnightly, although 1 excercise is substituted by a seminar), the rest of the term (2 weeks) is reserved for any topics that need more time and/or consulations. The length of each lecture/excercise is 105 minutes.

As of autumn 2015, Structural Design is a joint responsibility of **Block Research Group**[408] and the **Chair of Structural Design**[409]. Two year curriculum (**Structural Design I-IV**) has been created as a product of cooperation of those two departments with new and updated teaching materials as a result.

There were two senior lecturers (Prof. Block, Prof. Schwarz) to cover the subject in 2018/19, supported by one main teaching assistant per chair, and 12 koje assistants (lab assistants). The size of each lab group is between 10-15 students.

Learning goals of Structural Design (as stated on department website) are as follows:

- be able to apply basic structural principles
- with the help of a graphical method, be able to visualise possible force flows in structures

[407] the editor of widely used textbook: ***Constructing Architecture***, Birkhäuser, 4th edition 2008

[408] The **Block Research Group** (BRG) at the Technology in Architecture at ETH Zürich is led by Prof. Dr. Philippe Block and Dr. Tom Van Mele. Research at the BRG focuses on several core areas, including analysis of masonry structures, graphical analysis and design methods, computational form finding and structural design, discrete element assemblies, and fabrication and construction technologies. The central goals of their geometry-based approach are to understand the real demands of complex structural design and engineering problems and to develop new algorithms and efficient, accessible tools for structurally informed design. Source: https://www.block.arch.ethz.ch, visited June 2019.

[409] **Prof. Dr. Joseph Schwartz**
studied et ETH (civil eng.1981, doctoral degree 1989), pedagogical praxis at Swiss universities (1989-1999), professor at Lucerne University of Applied Sciences and Arts; associate partner at consulting office in Zug (1991-2001), project engineer for bridge and building structures; owner of civil eng. office in Zug since 2001; chairman of the Swiss structural masonry code comitee; co-authos of books: Design of Concrete Structures with Stress Fields" (1996) and "Mauerwerk" (1998). Source: ETH Zurich website, visited June 2019.

- to dimension structural elements for typical building materials whilst taking into account material properties and their design potential
- to have an understanding of a tectonic logic and construction methods of common assembly techniques and being able to apply it
- be able to analyse structures whilst using appropriate terminology and objective arguments
- be able to question structural design concepts of historical and contemporary references in a critical manner
- be able to design a suitable structural system for a task given whilst taking into account a wide range of possible inner force flow paths

Structural design book ***Faustformel Tragwerksentwurf***[410] by Philippe Block, Christoph Gengnagel and Stefan Peters[411] represents the main reading for the course, as an enhancement ***Form and Forces*** by Edward Allen and Waclaw Zalewski is further recommended.

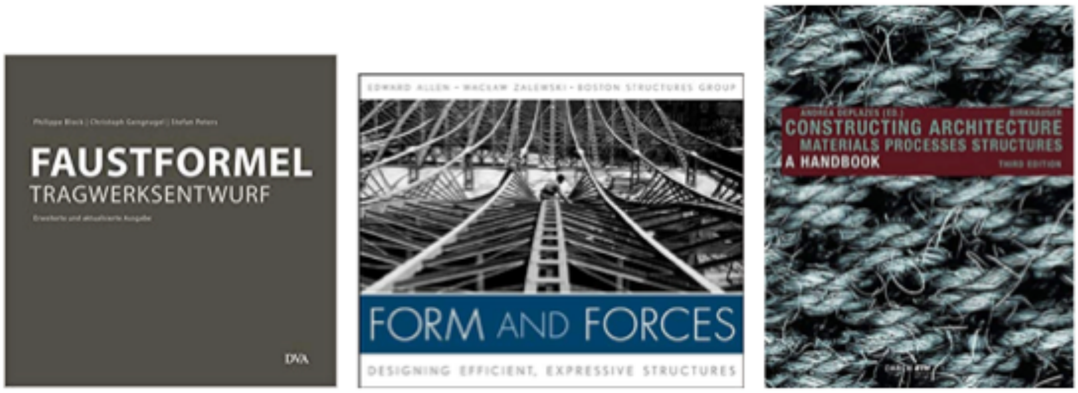

Fig. G1.2.1 a-c Textbooks used for the course Structural Design at ETH Zurich
Faustformel, BLOCK, P., GENGNAGEL, C., PETERS, S., 2013, (a)
Form and Forces, ALLEN,W., ZALEWSKI, W.,2009, (b)
Constructing Architecture, DEPLAZES, A.ed., 2018 (4th ed.), (c)

Faustformel summarizes the most important basics of structural design. It is based on the principles of structural analysis and strength theory and briefly explains how the internal forces of a beam and stresses of different cross-sectional shapes can be calculated. There is a chapter that presents all important basic structural systems (arch, truss, frame, cable, vault...) together with formulas for their approximate pre-dimensioning, another chapter is devoted to

[410] **Faustformel=Rule of thumb/Fist formel** - refers to the right-hand rule
[411] cooperation of several experienced university lecturers: Philipp Block and Marcel Aubert at the ETH Zurich (Switzerland), Christoph Gengnagel and Ines Prokop at the UdK in Berlin (Germany), Stefan Peters and Eva Pirker at the Graz University of Technology (Austria)

graphic methods, discussed is also stability, connections or material properties. It also contains a detailed analysis of selected real-life structures such as Waterloo Station or Gherkin building in London, United Kingdom or Salginatobel Bridge in Switzerland.

An important learning tool widely used at ETH is an interactive platform e**QUILIBRIUM**[412], which also contains detailed examples of how to use graphic statics (case studies, interactive drawings). See Fig.G1.2.13.

Structural Design I+II (Tragwerksentwurf I+II) courses introduce design and behaviour of structures and structural materials. **Great emphasis** is put onto the **development of a structural form** and on **principles of structural design.** Courses promote **creative approach to repetitive calculations - graphic statics**[413] [414], and **working with real physical structural models** is used in order to develop an intuitive understanding of a relationship between the shape of a structure, the load it needs to carry, and the forces in it.

These methods are demonstrated on cable and membrane structures, arch and shell structures and combine arch and cable systems. Acquired knowledge is then directly applied (to the roof system, bridges and buildings) in lectures, colloquia, hands-on exercises and projects.

There is **profesor Schwartz's scriptum *Tragwerksentwurf I,II*** (2011) at disposition together with detailed plan of all **lectures and excercises online**.[415] (See Fig. G1.2.2 for general overview of chapters and Fig. G1.2.3, Fig. G1.2.4 for an example how lecture or exercise is displayed online. The list of all Structural Design I+II lectures is presented in Fig. G1.2.14 followed by the their specification (Fig. G1.2.15- Fig.G1.2.20). During the exam, approach, constructions and final results are evaluated. Approximately 30% of the exam is about general questions, and approximately 70% of the exam is about calculations and drawings (see Fig. G1.2.21 for example).

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[412] an interactive environment for graphic statics based structural design

[413] allow the visualisation of internal and external forces in structural systems, therefore illustrate a relationship between shape/form and stress/force in load-bearing elements

[414] see p.77 for graphic statics principles

[415] http://www.block.arch.ethz.ch/eq/course/4 (Structural Design I), visited June 2019
http://www.block.arch.ethz.ch/eq/course/45 (Structural Design II), visited June 2019

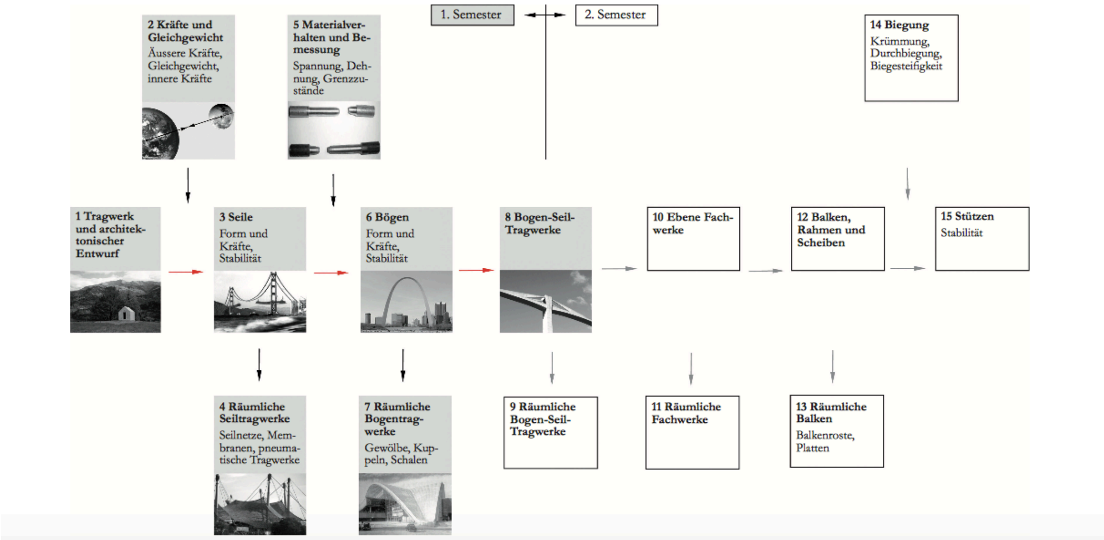


Fig. G1.2.2 Prof. Schwartz's online scriptum ***Tragwerksentwurf I+II***; chapter organisation

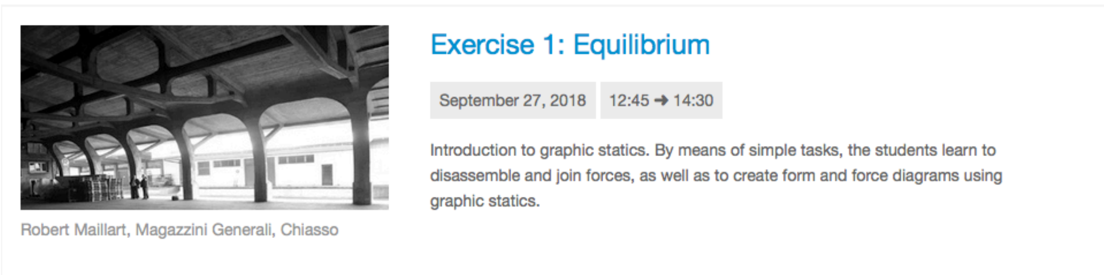


Fig. G1.2.3 example of how is Prof. Schwartz's lecture displayed online
Fig. G1.2.4 example of how is Prof. Schwartz's exercise displayed online
Detailed info containing all courses can be seen in Fig. G1.2.14 - Fig. G1.2.20.

Structural Design III+IV (Tragwerksentwurf III+IV) is a follow up SE course taken by students in the second year of their studies. Provided by the same departments, it further enhances SE knowledge. The course focuses on **essential building materials (concrete, steel, wood and masonry)** as well as on **foundation engineering**. More detailed info on the contents as well as an example of a page from the textbook can be seen in Fig. G1.2.22.

With the help of graphic statics methods (familiarised during the first year), material specific solutions with regard to structural questions are investigated on the basis of realised constructions. There is also an introduction to the numerical world of **Rhino** and **RhinoVault** systems in the form of workshops. Practical exercises dealing with targeted adjustments of structures according to a specific architectural situation are also regular components of these courses.

Analogically to the year 1 study materials, there is a **follow-up scriptum** for the course by **profesor Schwartz**: ***Tragwerksentwurf III,IV*** (2014), at disposition together with a detailed plan of all **lectures and excercises online**.[416] The overview of lectures is in Fig. G1.2.5, examples how the lecture/exercise is displayed online in Fig. G1.2.6 and Fig. G1.2.7. Detailed info on lectures' content can be seen in Fig G1.2.22 - Fig. G1. 2.26.

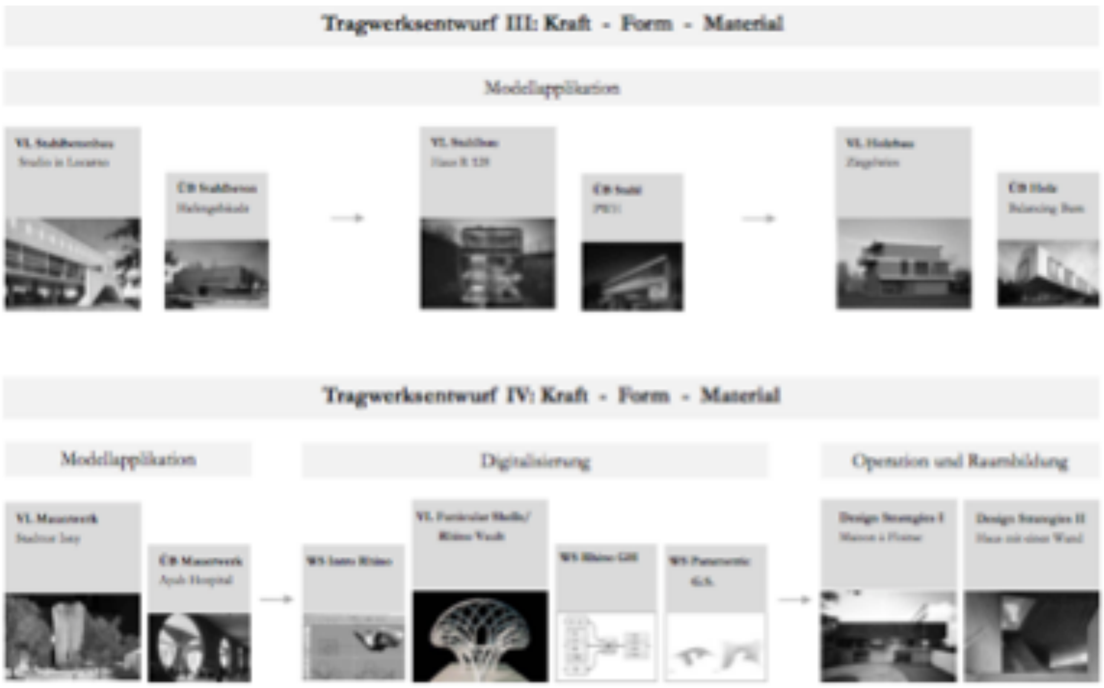


Fig. G1.2.5 Prof. Schwartz's online scriptum Tragwerksentwurf III+IV, chapter oraganisation

416 http://www.block.arch.ethz.ch/eq/course/81 (Structural Design III), visited June 2019
http://www.block.arch.ethz.ch/eq/course/121 (Structural Design IV), visited June 2019

Studio di Architettura Livio Vacchini, Locarno, 1985

Lecture 1: Reinforced Concrete

Based on the Studio of Livio Vacchini in Locarno, this lecture gives an introduction to reinforced concrete. We present the design concept of Vacchini. Additionally, the features of concrete are presented, concluded with interesting and outstanding examples of buildings made from concrete and exposed concrete.

Hafengebäude Rohner, Fußach, Österreich. Arch.: Baumschlager & Eberle, 2000

Exercise 1: Reinforced Concrete

In this exercise, the understanding of forces under varying load and support situations is to be developed. The exercise will deal with the design of the force-flow in a shear wall with openings.

Fig. G1.2.6 Prof. Schwartz's online lecture - intoductory page
Fig. G1.2.7 Prof. Schwartz's online exercise - introductory page
Detailed info containing all courses can be seen in Fig. G1.2.23 - Fig. G1.2.26.

Exam info for Structural Design III+IV is also displayed online[417].

Structural Design V[418] shifts the focus from material-related aspects to design-oriented aspects. It contains case studies and design exercises. **Structural Design VI**[419] is devoted to parametric modelling, to finding structural forms and to optimisation of structures. Rhino and Grasshopper digital tools are used. Both courses are optional.

"CONSTRUCTING EQUILIBRIUM" Project

As described in the conference paper by Vrontissi et al.[420], the project is based on educational practices that have been applied at ETH by the Chair of Structural Design since 2008, and is within the framework of the internal restructuralisation. Until the fall 2014, there was the Chair of Architecture and Structures responsible for Structures I+II (introduction to structural design by the means of graphic statics and physical models), and the Chair of Structural Design responsible for Structures III+IV. The two Chairs were then employed to jointly build and teach the whole structural curriculum within the Innovedum educational project. The second year of "the new" structural curriculum now concentrates on a specific design aspects

[417] http://www.block.arch.ethz.ch/eq/content/exam/120, visited June 2019
[418] source: http://www.block.arch.ethz.ch/eq/course/133, visited June 2019
[419] source: http://www.block.arch.ethz.ch/eq/course/154, visited June 2019
[420] VRONTISSI et al. (2018)

like materiality and technology of a building structure, when Structures III explores the design potential of common building systems, and Structures IV focuses on exemplary design strategies. Overall, the concept of the structural courses focuses now more on synthetic mode compared to the original analytical focus, and structural design is seen as a coaxion of the form, forces and material. Graphic statics represents the main foundation of the structural courses.

"Constructing Equilibrium" exercise was developed by L. Enrique, P. d'Acunto and J. Castellon under the supervision of Prof. J. Schwartz, was first tested during the spring semester of the year 2013-14 as a design project in Structures IV, and followed-up three additional years. The main idea behind the project was to implement typologically "new" 3D structural exercise. The inspiration for the project came from spatial compositions of objects in equilibrium by Swiss contemporary artists P.Fischli and D.Weiss. The assignment consisted of three steps. Students at first explored structural concepts by creating a spatial composition of objects in equilibrium, as a second step they applied structural concept from the composition to an architectural design, and as a last step they further developed the proposition from the material and technological aspects.

Step 1: Exploring structural concepts

Fig. G1.2.8 "Constructing Equilibrium" project: catalogue of objects

Students first had to choose four to six objects from a given catalogue of household items of various structural behaviour (Fig. G1.2.8), (chopsticks, toothpicks, a hammer, a bottle, a paper roll and a rolling pin as rods; headphones, laces, a metal wire and a rubber band as ties with various elastic properties; a handsaw, a ruler, a fork and a ladle as bending-active elements with varying flexural stiffness; coffee seeds, sugar cubes, an orange, a sponge and a balloon as volumetric elements with different self-weights) and material characteristics (metal, timber, plastic, fabric, organic objects)), and then had to create three types of spatial compositions in static equilibrium, each bearing a different structural principle (cantilevering, spanning, hanging), further accompanied by the strut-and-tie[421] schemes, displaying stresses and strains in the model. The household objects were also selected to display opposite features such as lightness vs. masivness, slenderness vs. stiffness or fragility vs. strength. The use of a tape or glue was not allowed. During this intentionally playful exercise students explored physical and material features of particular objects, intuitively worked out basic principles of static equilibrium, and came out with a set of hierarchical rules of where to put particular items within the composition. As reported in the paper, only about half of the projects suceeded in creating full 3D composition, the rest of them being actually 2-D schemes. Examples of sucessful compositions are in Fig. G1.2.9.

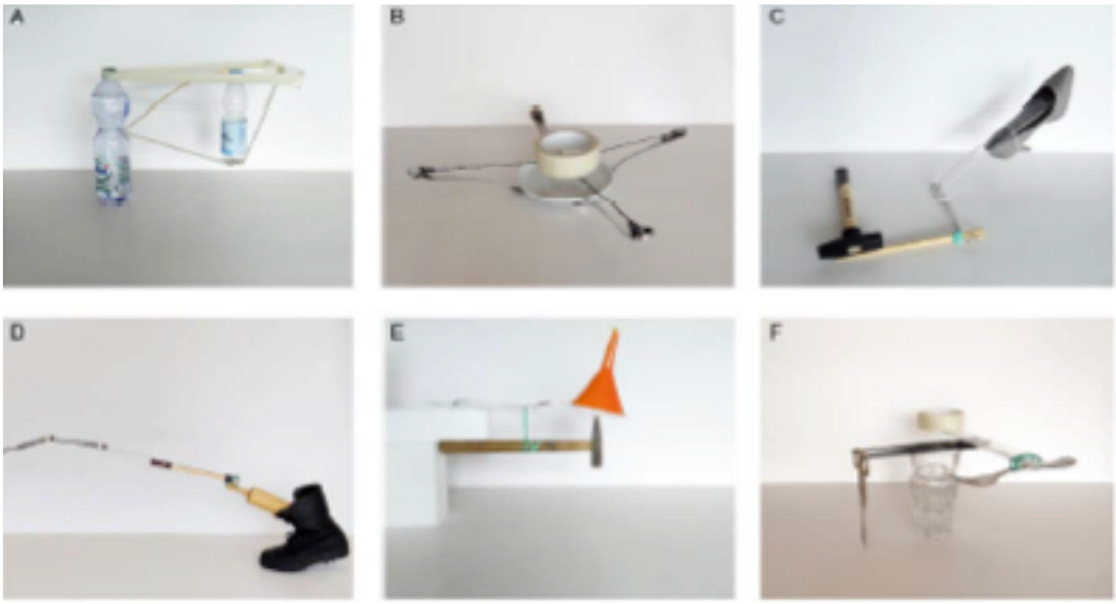


Fig. G1.2.9 "Constructing Equilibrium" project: examples of compositions of objects in equilibrium

Step 2: Application - using the structural concept for architectural design

In this step, students were challenged to transform their chosen structural configurations into an architectural proposal, which was further specified by the given type of the design (e.g. climbing wall, open cinema, reading rooms, baths, solarium, diving platform...), and requested to put into the specific site along the river in Zurich. Students had to produce sketches, drawings, diagrams, pictures or physical models documenting the transition process as well as renderings or collages displaying the structure being put into the chosen site.

[421] All structures have forces acting on them. You should have an understanding of tensile, compressive and shear forces (see previous sheet). The part of the structure that has a tensile force acting on it is called a **TIE** and the part that has a compressive force acting on it is called a **STRUT**.
source: www.technologystudent.com › struct1 › strut1, visited June 2019.

References supporting the design idea with the aims of the proposition emphasised were also requested to provide.

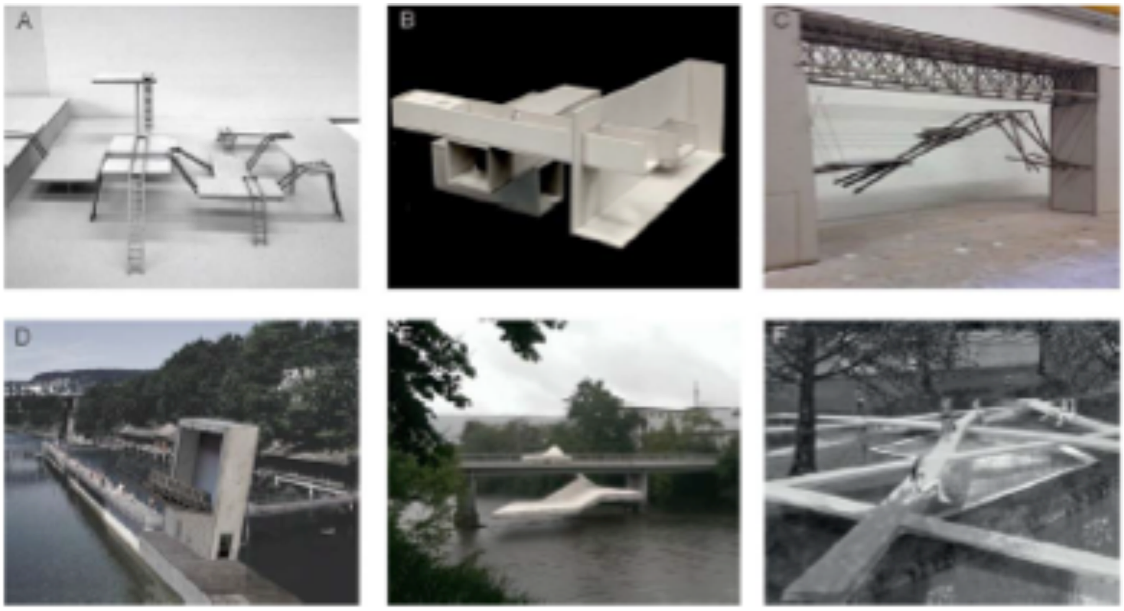


Fig. G1.2.10 "Constructing Equilibrium" project: programmatic and contextual transformations (step 2)

Step 3: Materializing the proposal

In the last phase, students had to develop their proposals into realizable projects by designing both the main structural parts and secondary architectural elements (circulation pathways, staircases...), and sometimes also the building envelopes. The emphasis was put onto the chosing an appropriate structural materials and technologies, and designing relevant structural details. During the process they had to take into account what type of structure would be the best for conveying the forces within, whilst further enhancing the architectural idea (e.g. what would be the best solution for realizing the beam: timber truss, steel profile, light-weight truss, reinforced concrete member...), and students were encouraged to explore and compare various options. Detailed physical models or visualisations were required to produce. Example is in Fig. G1.2.11.

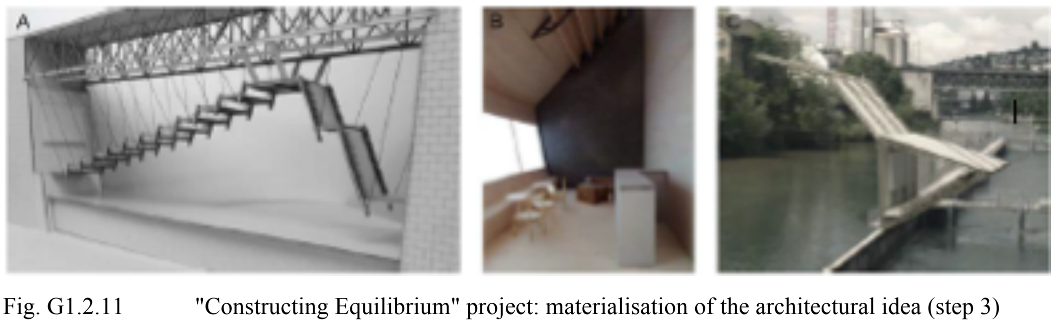


Fig. G1.2.11 "Constructing Equilibrium" project: materialisation of the architectural idea (step 3)

EXCURSIONS

Academic excursions organised by Department of Structural Design are taking place twice a year. The programme is meticulously planned for a small group of students (usually between 15-20) interested in particular theme. The group is always accompanied by selection of local experts - historians, engineers, academics, urban planners etc. Students not only perform on-site visits, but actively take part in various workshops, discussions or projects.

A trip to Nantes in spring 2019 for students aimed to show students what the future prospects for buildings that have lost their original function might be. Accompanied by a photography workshop, a seminar week traced ongoing architectural and urban transformations of Nante's wasteland. There was an aim for students to identify the qualities that make a structure able to withstand programmatic obsolence. Amongst many others, they visited one of the first famous henebique structures - the Moulins de la Loire or La Cité Radieuse de Le Corbusier.

Previous excursions followed for example the **natural form of concrete in Rome**, explored the integration of geometrical and **structural principles in the work of Gaudi** and his followers in Barcelona, observed and documented the **interplay between architecture and construction on examples from industrialist cities Manchester and Liverpool** and many **more.**

VIDEO

An interesting feature on the university's webpages is giving everyone a chance to view some of ETH's lectures (see Fig. G1.2.12). The selection is not yet satisfying (if you want to follow a complete course), but if you compare the volume of lectures posted back in 2011 (the oldest contribution) to those posted "today", it shows a promising trend.

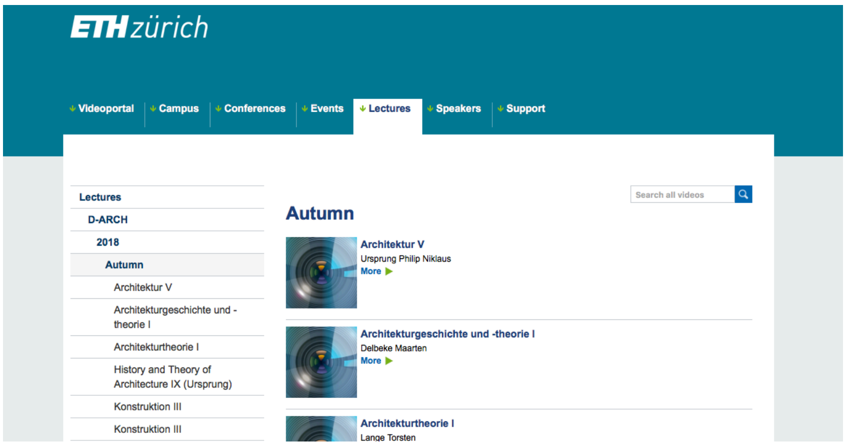
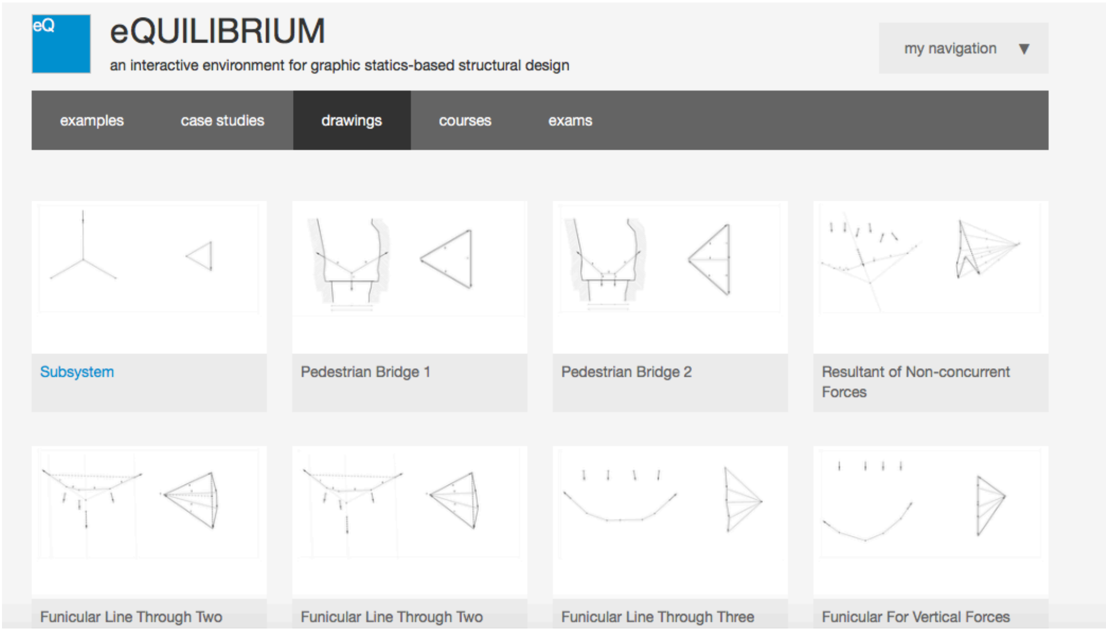


Fig. G1.2.12 ETH's webpage featuring selection of online lectures[422]

[422] retrieved in October 2018 from https://video.ethz.ch/lectures/d-arch.html



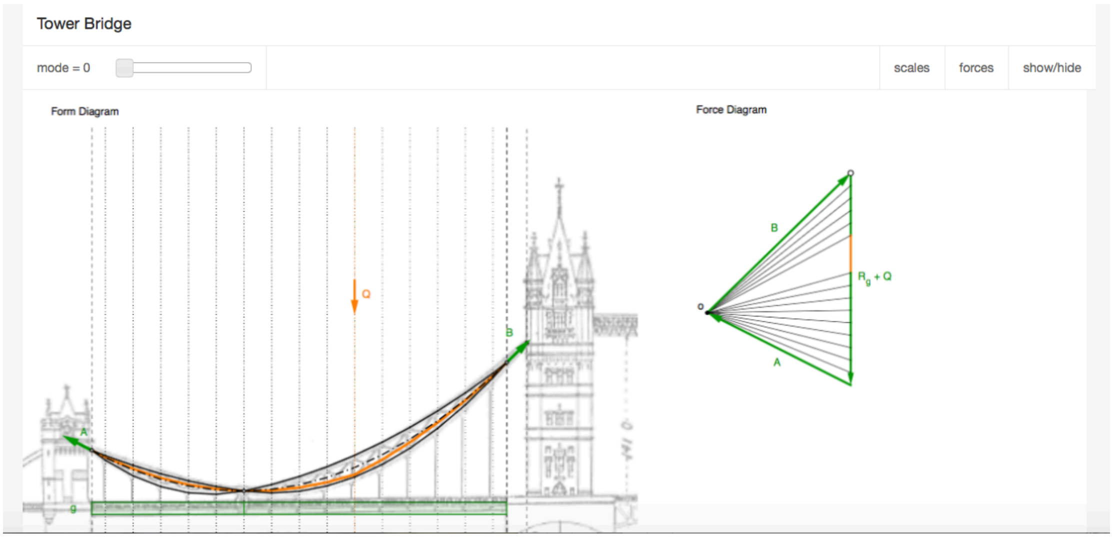
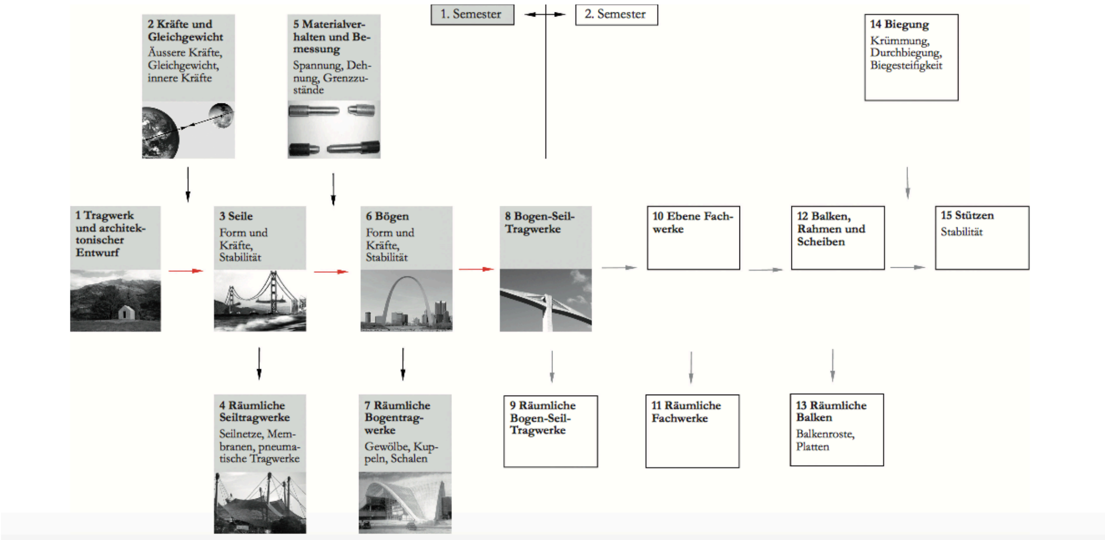


Fig G1.2.13 ETH's eQuilibrium interactive platform[423]

[423] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/drawing

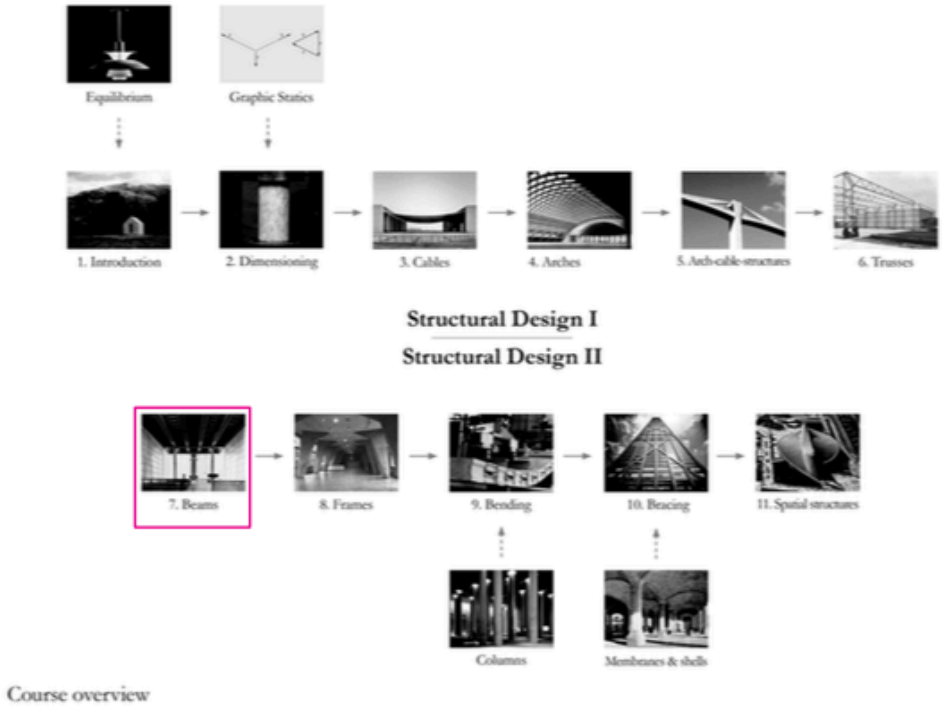


List of chapters

1. Tragwerk und architektonischer Entwurf / **Structure and architectural design**
2. Kräfte und Gleichgewicht / **Forces and balance**
3. Seile / **Cables**
4. Räumliche Seiltragwerke / **Spatial cable structures**
5. Materialverhalten und Bemessung / **Material behavior and design**
6. Bögen / **Plates**
7. Räumliche Bogentragwerke / **Spatial arch structures**
8. Bogen-Seiltragwerke / **Arches and cable structures**
9. Räumliche Bogen-Seil-Tragwerke / **Spatial arch cable structures**
10. Ebene Fachwerke / **Level trusses**
11. Räumliche Fachwerke / **Spatial trusses**
12. Balken, Rahmen und Scheiben / **Beams, frames and discs**
13. Räumliche Balken / **Spatial bars**
14. Biegung / **Bending**
15. Stützen / **Supports**

Fig. G1.2.14 Prof. Schwartz's online scriptum for Structural Design I+II [424]

[424] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/files/SchwartzSkriptTE_1_2_1507219782.pdf



Structural Design I

EN DE

Fall 20.09.2018 ➔ 06.12.2018

Structural Design I helps to develop an intuitive understanding of the relationship between the shape of a structure, the load it needs to carry and the forces in it. For administrative questions, please contact the teaching team of chair Block.

info this week schedule lectures exercises projects

Christian Kerez: Kapelle St. Nepomuk, Oberrealta, 1992

Lecture 1: Introduction

September 20, 2018 12:45 ➔ 14:30

This lecture introduces Structural Design by taking lessons and inspirations from the past. Through examining the works of master builders and structural artists, such as Gaudi, Eiffel, Maillart and Isler, we have a first look at the difference between structural forms, geometrical forms and clarity of form – can one easily follow the flow of forces through a structure? We learn that studying structures allows us to understand the built environment around us, and to design works of structural art. Furthermore, the dialogue between architecture and structure will be contextualised within contemporary Swiss architecture with case studies of Peter Zumthor and Christian Kerez.

Fig. G1.2.15 Prof. Schwartz's online Structural Design I+II course, p. 1/6[425]

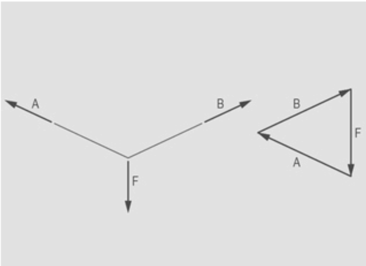
[425] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/4

Robert Maillart, Magazzini Generali, Chiasso

Exercise 1: Equilibrium

September 27, 2018 | 12:45 ➜ 14:30

Introduction to graphic statics. By means of simple tasks, the students learn to disassemble and join forces, as well as to create form and force diagrams using graphic statics.



Graphische Statik

Lecture 2: Dimensioning and Graphic Static

October 4, 2018 | 12:45 ➜ 14:30

This lecture covers forces and equilibrium, and an introduction to graphic statics. The basics about forces, static equilibrium and the principle of action equals reaction are introducted.

Eero Saarinen, Dulles Airport, Washington

Exercise 2: Dimensioning and Graphic Static

October 11, 2018 | 12:45 ➜ 14:30

The basics of graphic statics are practiced with simple cable structures. The first exercise showed how to combine resp. exclude forces, how to create an equilibrium and how cable structures react to different loads. This exercise is a deepening of graphical methods, again with cable structures. In general, dimensioning also needs to take into account the properties of the material to be used. The aim of the assessment is to determine the capacity and optimum size of a member by the means of arithmetic calculations.

Alvaro Siza: Expo-Pavilion, Lisabon, 1998

Lecture 3: Cable Structures

October 18, 2018 | 12:45 ➜ 14:30

This lecture covers the equilibrium of cable structures. A series of simple examples is used to introduce the terminology and factors which are relevant to the structural behaviour (pole, rise, types of loading). At the beginning of the lecture a first case study immediately develops into a sophisticated cable structure with possible applications ranging from elegant bridges to efficient roofs.

Frei Otto, Olympiastadion, München

Exercise 3: Cable Structures

November 1, 2018 | 12:45 ➜ 14:30

In the last exercise, simple cable structures were studied. The following exercise helps you to deepen your knowledge about form finding and more complex cable structures. You have to find thrust lines (cable forms) for cable structures with different loads.

Fig. G1.2.16 Prof. Schwartz's online Structural Design I+II course, p. 2/6[426]

[426] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/4

Robert Maillart: Valtschielbachbrücke, Donath, 1925

Lecture 4: Arches

November 8, 2018 12:45 ➜ 14:30

This lecture is based on the principle of inverting tension to compression – hanging cables are inverted into standing arches. Two-dimensional structures in masonry such as arches and buttresses are discussed.

Samyn and Partners, M&G Research Laboratory, Venafro

Exercise 4: Arch Structures

November 15, 2018 12:45 ➜ 14:30

This exercise involves arches and thrust lines. As it is the case for suspension cables, the arch shape also follows the load (thrust line). Therefore, all previous methods are also applicable to an arch. What is new are the initial investigations on support reactions.

Christian Menn: Ganterbrücke, Brig, 1980

Lecture 5: Arch-Cable Structures

November 22, 2018 12:45 ➜ 14:30

This lecture demonstrates the structural behaviour of arch-cable structures as a combination of funicular arches and cables. To illustrate how arch-cable structures work, the relationship between their load-bearing behaviour and support conditions is investigated in a step-by-step manner. The found principle can be applied to different structural boundary conditions.

Nicholas Grimshaw, Waterloo Station, London, UK

Exercise 5: Arch-Cable Structures

November 29, 2018 12:45 ➜ 14:30

In this exercise, the learnt methods of graphic statics are applied to hybrid arch-cable structures. Special attention is paid to determining the reaction forces for different structures and load cases.

Renzo Piano, Richard Rogers: Centre Georges Pompidou, Paris, France, 1977

Lecture 6: Trusses

December 6, 2018 12:45 ➜ 14:30

In this lecture the focus is on both the introduction to the technical terminology as well as on the subject of statical determinacy of structures. Furthermore, with the help of a case study, a systematic and progressive approach for the analysis of statically determinate trusses is explained. The structural behavior of trusses will be discussed. Trusses are explained as a combination and sequence of simple arch- cable structures. Similar to arch-cable structures, geometric variations are examined and discussed here. Furthermore, with the help of a case study, a systematic and progressive approach for the analysis of statically determinate trusses is explained.

Fig. G1.2.17 Prof. Schwartz's online Structural Design I+II course, p. 3/6[427]

[427] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/4

Structural Design II

EN DE

Spring | 22.02.2018 → 17.05.2018

Structural Design II completes the catalog of classical structural typologies and provides a safe handling of different models for the description of characteristic structural behavior. For administrative questions, please contact the teaching team of chair Block.

info | this week | schedule | lectures | exercises | projects

Ludwig Mies van der Rohe: Crown Hall, Chicago, USA, 1956

Exercise 06: Trusses and Beams

March 1, 2018 | 12:45 → 14:30

In this exercise, the statical determinacy of trusses is investigated. Then in the last task, the distribution of internal forces within beams is examined and the advantages and disadvantages of different possible solutions are discussed. For this purpose, arch-cable and truss analogies are used, i.e. the acquired knowledge about arch-cable structures and trusses is applied. In addition, the implication of intersecting members in the form diagram on the force diagram is studied.

Ensamble Studio, Hemeroscopium House, Madrid

Lecture 07: Beams

February 22, 2018 | 12:45 → 14:30

This lecture explains internal force distributions within beams with the help of discretized arch-cable and truss- models. Using this analogy, the final step to continuous stress fields and its development specifically to material is discussed.

Ensamble Studio, Hemeroscopium House, Madrid

Exercise 07: Beams and Frames

March 15, 2018 | 12:45 → 14:30

In this exercise, the distribution of internal forces within beams and frames is examined. First for the simple beam, then for beams with different support conditions and cantilevered beams. In addition, the implication of intersecting members in the form diagram on the force diagram is studied.

Wiskind, Sdwisdom, Qingdao, China

Lecture 08: Frames

March 15, 2018 | 12:45 → 14:30

By means of the already acquired knowledge, this lecture examines the possibility of force distributions within a frame structure. It specifically addresses the need for force deviation in the corners of frames. Furthermore, a load case within a hinged frame is extensively studied.

Fig. G1.2.18 Prof. Schwartz's online Structural Design I+II course, p. 4/6[428]

[428] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/45

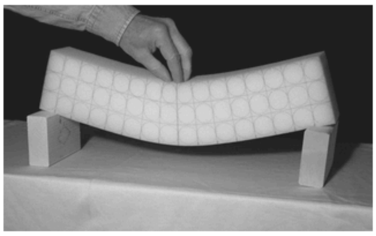
 Studio Vacchini architetti: Sporthalle Mülimatt, Windisch, 2010	**Exercise 08: Frames and Bending** April 12, 2018 12:45 ➔ 14:30 In this exercise, bending is examined. Moments can occur in general structures that deviate from the ideal form. Likewise, the static determinacy of different support situations and possible inner force distribution in reinforced concrete frames are discussed.
 Bending of a foam beam	**Lecture 09: Bending** March 29, 2018 12:45 ➔ 14:30 The thrust line as the optimal funicular shape is transferred to the design of efficient frame structures. The forces in frames are examined by looking at the deviation of the thrust line from the main axis of the actual geometry. / Starting from the two-dimensional thrust line, its single dimensional analogy is considered within a beam. The translation of compression and tension to a moment is further illustrated. / Based on the understanding of the axial stress-strain relationship, in this lecture the deflection is described as a relationship of compression, tension and curvature. In addition, the efficiency of different types of structures will be discussed by the inclusion of material dependencies. Based on the understanding of the axial stress-strain relationship, in this lecture the deflection is described as a relationship of compression, tension and curvature. In addition, the efficiency of different types of structures will be discussed by the inclusion of material dependencies.
 Richard Rogers, PAT Center, Princeton, USA	**Exercise 09: Case Study 1** April 26, 2018 12:45 ➔ 14:30 In this case study, we analyze the PAT Center of Richard Rogers and Ove Arups & Partners structural engineering. The PAT Center in Princeton, NJ, USA is a single-storey building with a floor area of 3,700 m2. Specializing in design and telecommunications, PA Technology LTD wanted the most flexible and expandable space possible as a technological center that could be adapted to unpredictable space requirements. That is why the building consists of a single large room, which can be subdivided as desired. Along the central axis, there are serially distributed pylons from which the roof is suspended. Task
 Renzo Piano: Bigo, Genua, Italy, 1992	**Lecture 10: Columns and Bracing** April 19, 2018 12:45 ➔ 14:30 In this lecture, columns as one of the last major structural typologies is presented. Besides the influence of the support conditions and material stiffness, special attention is paid to the nature of the instability problem by buckling.

Fig. G1.2.19 Prof. Schwartz's online Structural Design I+II course, p. 5/6[429]

[429] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/45

Capilla abierta, Lomas de Cuernavaca, Mexiko, Felix Candela, 1959

Lecture 11: Spatial structures

May 3, 2018 12:45 ➜ 14:30

The lecture looks at structural types, which are derived from arch-cable structures such as cable-stayed structures and tree structures. In the next step, spatial arch-cable structures are discussed. What appear to be spatially complex structures can be once again explained using the learnt two-dimensional methods. The lecture concludes with an excursion into the world of spatial trusses.

PAT Center - Structure

Exercise 10: Case Study 2

May 17, 2018 12:45 ➜ 14:30

In this case study, we analyze the PAT Center of Richard Rogers and Ove Arups & Partners structural engineering. The PAT Center in Princeton, NJ, USA is a single-storey building with a floor area of 3,700 m2. Specializing in design and telecommunications, PA Technology LTD wanted the most flexible and expandable space possible as a technological center that could be adapted to unpredictable space requirements. That is why the building consists of a single large room, which can be subdivided as desired. Along the central axis, there are serially distributed pylons from which the roof is suspended.

Fig. G1.2.20 Prof. Schwartz's online Structural Design I+II course, p. 6/6
source: http://www.block.arch.ethz.ch/eq/course/45
visited June 2019

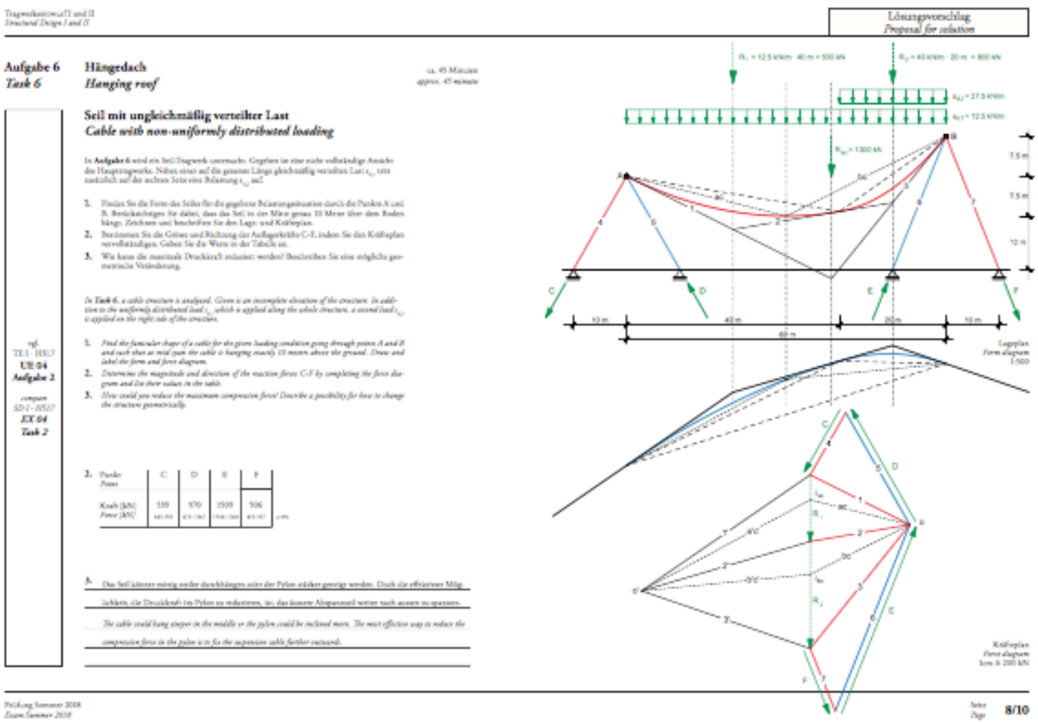
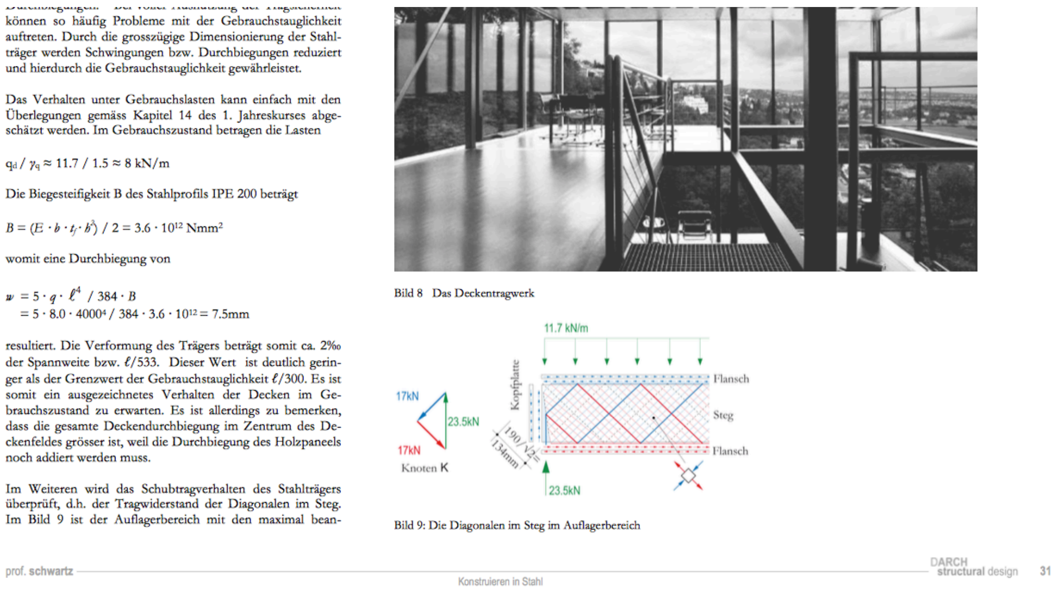


Fig. G1.2.21 page from the Structural Design I+II exam[430]

[430] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/content/exam/120

List of chapters



können so häufig Probleme mit der Gebrauchstauglichkeit auftreten. Durch die grosszügige Dimensionierung der Stahlträger werden Schwingungen bzw. Durchbiegungen reduziert und hierdurch die Gebrauchstauglichkeit gewährleistet.

Das Verhalten unter Gebrauchslasten kann einfach mit den Überlegungen gemäss Kapitel 14 des 1. Jahreskurses abgeschätzt werden. Im Gebrauchszustand betragen die Lasten

$q_d / \gamma_q \approx 11.7 / 1.5 \approx 8$ kN/m

Die Biegesteifigkeit B des Stahlprofils IPE 200 beträgt

$B = (E \cdot b \cdot t_f \cdot h^2) / 2 = 3.6 \cdot 10^{12}$ Nmm²

womit eine Durchbiegung von

$$w = 5 \cdot q \cdot \ell^4 / 384 \cdot B$$
$$= 5 \cdot 8.0 \cdot 4000^4 / 384 \cdot 3.6 \cdot 10^{12} = 7.5\text{mm}$$

resultiert. Die Verformung des Trägers beträgt somit ca. 2‰ der Spannweite bzw. ℓ/533. Dieser Wert ist deutlich geringer als der Grenzwert der Gebrauchstauglichkeit ℓ/300. Es ist somit ein ausgezeichnetes Verhalten der Decken im Gebrauchszustand zu erwarten. Es ist allerdings zu bemerken, dass die gesamte Deckendurchbiegung im Zentrum des Deckenfeldes grösser ist, weil die Durchbiegung des Holzpaneels noch addiert werden muss.

Im Weiteren wird das Schubtragverhalten des Stahlträgers überprüft, d.h. der Tragwiderstand der Diagonalen im Steg. Im Bild 9 ist der Auflagerbereich mit den maximal bean-

Bild 8 Das Deckentragwerk

Bild 9: Die Diagonalen im Steg im Auflagerbereich

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Fig. G1.2.22 Prof. Schwartz's online scriptum for Structural Design III+IV, contents and an example of a page[431]

[431] retrieved in June 2019 from http://schwartz.arch.ethz.ch/Vorlesungen/TE_3_4/Dokumente/SchwartzSkriptTE_3_4.pdf?lan=de

Structural Design III

EN DE

Fall semester 21.09.2018 → 07.12.2018

Structural Design III deals with the relationship between force, form and material. In particular the materials reinforced concrete, steel, timber and masonry will be discussed. For administrative questions, please contact the teaching team of chair Schwartz.

info this week schedule **lectures** exercises projects

Studio di Architettura Livio Vacchini, Locarno, 1985

Lecture 1: Reinforced Concrete

Based on the Studio of Livio Vacchini in Locarno, this lecture gives an introduction to reinforced concrete. We present the design concept of Vacchini. Additionally, the features of concrete are presented, concluded with interesting and outstanding examples of buildings made from concrete and exposed concrete.

Hafengebäude Rohner, Fußach, Österreich. Arch.: Baumschlager & Eberle, 2000

Exercise 1: Reinforced Concrete

In this exercise, the understanding of forces under varying load and support situations is to be developed. The exercise will deal with the design of the force-flow in a shear wall with openings.

Werner Sobek: R128, Stuttgart, 2000

Lecture 2: Steel

This lecture covers the use of the material steel based on the house R 128 by Werner Sobek Stuttgart. In this lecture, the design concept, the ceiling, the supports and the design features with respect to wind and earthquakes, and bolted and welded connections are discussed. Additionally, the properties of structural steel, the profile types and their application as well as the corrosion and fire protection are treated.

Picture Window House, Shizuoka, Japan, 2002, Arch.: Shigeru Ban

Exercise 2: Steel

This exercise deals with the inner flow of forces in trusses. In particular, it discusses steel constructions. As example, the Picture Window House by Shigeru Ban will be examined.

Fig. G1.2.23 Prof. Schwartz's online Structural Design III+IV course, p.1/4[432]

[432] source: http://www.block.arch.ethz.ch/eq/course/81, visited June 2019

Wohnüberbauung Ziegelwies, Altendorf, 2003,
Arch.: M. Burkhalter und C. Sumi

Lecture 3: Timber

The material timber is illustrated by considering the Wohnüberbauung Ziegelwies of Burkhalter Sumi Architects. The design concept is here particularly described. Furthermore, a closer look at ceiling and screw is placed. The specialities regarding walls and columns as well as wind and earthquakes are emphasised. The properties of wood and various wood constructions are then explained.

Balancing Barn, Thorington, Suffolk, UK, 2011.
Arch.: MVRDV

Exercise 3: Timber

The material timber and horizontal load cases are discussed with the example of the Balancing Barn. The design relates its shape, but also its structural design to the barn architecture, which is native to the surrounding county.

Parlamentsgebäude, Sher-e-Banglanagar, Dhaka, Bangladesch,1962-1974, Louis I. Kahn

Lecture 4: Masonry

This lecture on the use of masonry in Louis Kahn's work has a special attention to his work in Bangladesh. The use of masonry is constructively discussed and the sensible and appropriate use of masonry clarified. A second part focuses on the specific material properties of masonry and gives a historical review. Furthermore, the design for the gate Isny by Peter Zumthor is discussed.

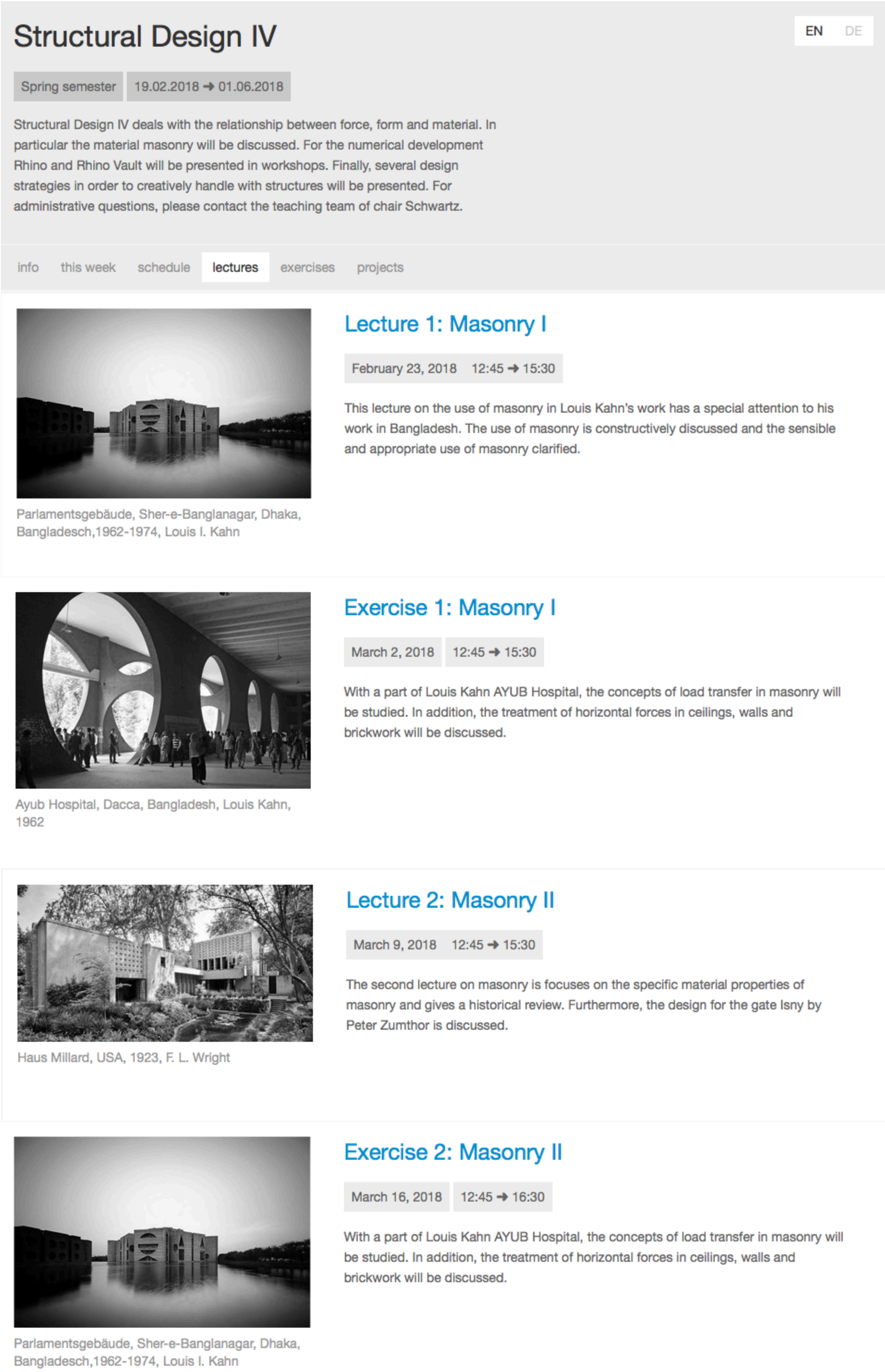
Ayub Hospital, Dacca, Bangladesh, Louis Kahn, 1962

Exercise 4: Masonry

With a part of Louis Kahn AYUB Hospital, the concepts of load transfer in masonry will be studied. In addition, the treatment of horizontal forces in ceilings, walls and brickwork will be discussed.

Fig. G1.2.24 Prof. Schwartz's online Structural Design III+IV course, p. 2/4[433]

[433] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/81



Structural Design IV

EN DE

Spring semester | 19.02.2018 ➔ 01.06.2018

Structural Design IV deals with the relationship between force, form and material. In particular the material masonry will be discussed. For the numerical development Rhino and Rhino Vault will be presented in workshops. Finally, several design strategies in order to creatively handle with structures will be presented. For administrative questions, please contact the teaching team of chair Schwartz.

info | this week | schedule | lectures | exercises | projects

Parlamentsgebäude, Sher-e-Banglanagar, Dhaka, Bangladesch,1962-1974, Louis I. Kahn

Lecture 1: Masonry I

February 23, 2018 | 12:45 ➔ 15:30

This lecture on the use of masonry in Louis Kahn's work has a special attention to his work in Bangladesh. The use of masonry is constructively discussed and the sensible and appropriate use of masonry clarified.

Ayub Hospital, Dacca, Bangladesh, Louis Kahn, 1962

Exercise 1: Masonry I

March 2, 2018 | 12:45 ➔ 15:30

With a part of Louis Kahn AYUB Hospital, the concepts of load transfer in masonry will be studied. In addition, the treatment of horizontal forces in ceilings, walls and brickwork will be discussed.

Haus Millard, USA, 1923, F. L. Wright

Lecture 2: Masonry II

March 9, 2018 | 12:45 ➔ 15:30

The second lecture on masonry is focuses on the specific material properties of masonry and gives a historical review. Furthermore, the design for the gate Isny by Peter Zumthor is discussed.

Parlamentsgebäude, Sher-e-Banglanagar, Dhaka, Bangladesch,1962-1974, Louis I. Kahn

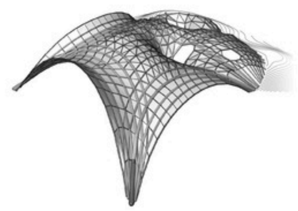
Exercise 2: Masonry II

March 16, 2018 | 12:45 ➔ 16:30

With a part of Louis Kahn AYUB Hospital, the concepts of load transfer in masonry will be studied. In addition, the treatment of horizontal forces in ceilings, walls and brickwork will be discussed.

Fig. G1.2.25 Prof. Schwartz's online Structural Design III+IV course, p. 3/4[434]

[434] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/121



MLK Jr. Park Stone Vault, Austin, TX, USA, Block Research Group ETH Zurich

Workshop 1: Intro Rhino

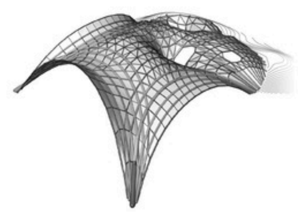
April 13, 2018 12:45 ➜ 16:30

This three-week workshop serves as a introduction to the digitalization of architecture. The program Rhino and RhinoVault will be presented and the special features in three-dimensional modelling are discussed. You will be able to design spectacular shapes for shells intuitively and with the knowledge of the form and force diagram.

Armadillo Vault at Beyond Bending exhibition, Venice Biennale, 2016, Block Research Group ETH Zurich

Lecture 3: Funicular Shells

April 20, 2018 12:45 ➜ 16:30

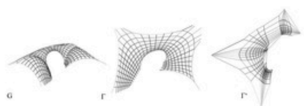


MLK Jr. Park Stone Vault, Austin, TX, USA, Block Research Group ETH Zurich

Workshop 2: Rhino GH

April 27, 2018 12:45 ➜ 16:30

This workshop serves as a first introduction to the digitization of Architecture. To this extend, the program Rhion will be presented and the special features in three-dimensional modelling are discussed.



Free-form Catalan Thin-tile vault, Zurich, Switzerland, Block Research Group ETH Zurich

Workshop 3: Parametric Graphic Statics

May 4, 2018 12:45 ➜ 16:30

In this workshop the Rhino plugin Rhino Vault is presented. With this program, spectacular shapes for shells can be designed intuitively and with the knowledge of the form and force diagram.

Maison à Floirac, Frankreich, 1998, Rem Koolhaas, Cecil Balmond

Lecture 4: Design Strategies I

May 11, 2018 12:45 ➜ 16:30

Lecture 5: Design Strategies II

May 18, 2018 12:45 ➜ 16:30

Sancho-Madridejos: Capilla, Valleaceron, Spain, 1997-2000

Fig. G1.2.26 Prof. Schwartz's online Structural Design III+IV course, p. 4/4[435]

[435] retrieved in June 2019 from http://www.block.arch.ethz.ch/eq/course/121

BARTLETT SCHOOL OF ARCHITECTURE, UCL, LONDON, UK

The Bartlett School of Architecture became part of Unversity College London (UCL) in 1841. UCL offered a secular alternative to the religious universities of Oxford and Cambridge, and was the first English university that made its courses available to people regardless of religious belief, social status and gender. The Bartlett is also one of the first institutions offering urban planning (since 1914).[436]

The Bartlett School of Architecture at UCL London offers following architectural undergraduate courses: Architecture BSc (K100), Architectural and Interdisciplinary Studies BSc (K102), Architectural and Interdisciplinary Studies with a Year Abroad BSc. (K 101), Architecture MSci (K 103) and Engineering and Architectural Design MEng (KH 11) 4 years. Content of the courses varies, but emphasis on a studio work (taught through individual design projects, one-to-one weekly tutorials, and frequent review sessions) is what they have in common. Internal study credits double the value of ECTS. There are 3 study terms: end of September to mid December, January to end of March and end of April to the beginning of June.

The Bartlett School of Architecture has taken **the first place in QS 2019 world** ranking by subject.

Architecture BSc [437] takes 3 years to complete and is awarded 60 ECTS per year.
Year 1 is centered on **Design Studio project** (30 ECTS), which consists of a smaller scale project in the first term, and loosely connected design of a building of larger scale in the second term. The project **does not focus on structural aspects of the design**. Other four modules are represented by subjects on: history, city planning, environment and technology (there is one technical subject in each year curriculum). **Structures, Materials and Forming Techniques** (7.5 ECTS) is coordinated by **Steve Johnson** and **Anderson Inge**, and is specialised on material properties. As a coursework, a **technical analysis of a building** must be carried out (selected from a list, not connected with the Desin Studio). A **field trip to a major European city** in the second term is also compulsory part of a year 1 curriculum.
There are 4 core modules in year 2, and 3 core modules in year 3. The most important of them is the **Design Studio** in **years 2 and 3** (37.5 ECTS each year) , further complemented by

[436] source: university's website
[437] https://www.ucl.ac.uk/bartlett/architecture/programmes/undergraduate/bsc-architecture, visited July 2019

series of lectures, workshops and seminars. For the studio project, students join one of the thirteen "**Units**"[438] according to their personnal interests. There are three stages of work each year, and particular student's work might be inspired by the unit's annual field trip. The project could be in one of the following forms: 1:1 installation, material testing, speculative drawing, animation, models - digital or physical, etc.). **Structural design** in the second and third year is **connected to the design project**. Design studio in year three represents student's dissertation project.

Design Technology modul is part of the core subjects in both year 2 and 3. The subject is awarded 7.5 ECTS in year 2, and under the guidance of **Oliver Houchell** concentrates on selections of suitable materials and on structural strategies. Year three's coordinator is **Luke Olsen**, the subject is awarded 15 ECTS and specializes in determining the key technical issues, learning to carry out technical research, and on learning how to test, analyse and evaluate construction techniques.

70% of the programme is taught through a series of design projects and **assessed** through combination of coursework and design portfolio, technology modules are assessed through a combination of coursework, essays and examinations.

Architectural & Interdisciplinary studies BSc [439] course takes also 3 years to complete, and is awarded 60 ECTS credits (120 internal credits) per year.

Compared to pure architectural course, there is no Design Studio project, instead of it, there is a **Design and Creative Practice** (awarded between 7.5 to 22.5 ECTS each year), where architecture is only one of the topics from cultural and social scene, which are atken into focus. Architectural media specializes in drawing, photography, casting and model making. History of architecture is also studied, but there are **practically no technical subjects** in the curriculum.

Undergraduate programme **Engineering & Architectural Design MEng**[440] lasts 4 years. Programme director is Luke Olsen.

Compared to "architecture only" course, it is more technically orientated. The **first year** curriculum comprises of 7 modules, and is focused on building scientific basis for further

[438] established in 1990s in order to allow students to follow their personnal interests. Groups of 15-17 students from various year groups. Follow a new theme each year: e.g. Urban Cliff, Surrender to the Seasons etc.

[439] https://www.ucl.ac.uk/bartlett/architecture/programmes/undergraduate/bsc-architectural-studies, visited July 2019

[440] https://www.ucl.ac.uk/bartlett/architecture/programmes/undergraduate/engineering-architectural-design-meng, visited July 2019

studies with core courses on mathematics and engineering. 15 ECTS is devoted to **Materials, Mechanics and Making** led by **Dr Fabio Freddi**, 7.5 ECTS to Design Make Information lead by **Klaas de Rycke**, and 7.5 ECTS to **Design Make Live lead** by **Luke Olsen**. In the last course, students work in groups, and have to design, prototype and test and original and an innovative **pavilion in 1:1 scale**.

Students spend a **half of their study time** working in **Design Studio since year 2**. Design Practice has 30 ECTS credits, and is coordinated by Matthew Butcher. It is one of the 5 core subjects in year 2, another one of which is **Structural analysis and foundations design** (7.5 ECTS) specializing in a behaviour of structural elements. Structural Analysis is lead by **Dr Fabio Freddi**.

Analogically to pure architectural course, students work in "**Units**" since **year 3**. **Design practice** is one of the 5 core subjects in year 3 and takes 30 ECTS credits (coordinated by **Luke Olsen**). **Mechanics of Buildings** (7.5 ECTS) is taught by **Dr Yasemin Didem-Aktas**, and concentrates on applying an advanced structural analysis methods, numerical simulations, and working with lab-based models. **Making Buildings** (7.5 ECTS, taught by **Prof Dejan Mumovic**) also looks at the structures, but from a differnt perspective, as students have to evaluate a "deconstructed" building.

Finally, there is only one core (compulsory) subject appart from the **Dissertation** in the **year 4**: **Design Practice** (30 ECTS, coordinated by **Luke Olsen**), when students continue to work in Units.

There is a selection of optional courses, e.g. on **Advance Structural Design and Use of Parametric Modelling** as far as statics subjects are concerned.

Architecture MSci[441] undergraduate course, lasts 5 years. It has got a different structure of subjects in years 1-3 compared to other architectonical study programmes, but also puts a great emphasis on project work. Programme director is Sara Shaflei. Compared to Architecture BSc., this programme is more technically and project orienated.

There are 6 modules in **Year 1**, including **Structural Concepts and Tools** (7.5 ECTS). With the exception of history subject in **year 2**, all the remaining subjects are in the form of a Project (45 ECTS alltogether) or a Professional Report (7.5 ECTS). **Year 3** is devoted to Research by Design (37.5 ECTS alltogether), Theory Dissertation (15 ECTS) and to Personnal Skills Portfolio (7.5 ECTS). **Year 4** curricullum assigns 52.5 ECTS to various forms of projects, with 7.5 ECTS left to history course, and in **year 5** student can choose

[441] https://www.ucl.ac.uk/bartlett/architecture/programmes/undergraduate/architecture-msci , visited July 2019

between paid Practice/Research Placement ot two modules. Master thesis must be also produced.
Assessment of the design is done through the portfolio, written coursework is marked and students receive a feedback. There is also a placement record to submit for final examinations if applicable.

There are various specialised **master postgraduate courses programmes**: Architecture MArch is a sequel to Architecture BSc, takes further 2 years and predominantly awards its study credits to the Design Projects. Master Thesis takes place in year 5.
To name just a few other possibilities, there are some master courses taking an additional year, e.g. Architectural Design MArch course, or Architectural Computation course (MRes or MSc variation).

ADDITIONAL ACTIVITIES

Each year, after the end of the last term, there is an exhibition of students's work called **Summer Show**, which lasts approximately 2 weeks and is accompanied by the exhibition catalogue[442] (Fig. G1.3.1, G1.3.2).

Fig. G1.3.1 The Summer Show at Bartletts
Fig. G1.3.2 Summer Show catalogues

The Bartlett Summer school[443] has been taking place since 2011 and is intended for 16-18 year old students, who are interested in architectural studies. Students work either in a small groups, or individually, and all participate at the end of week's joint exhibition. It lasts either 5 days, 10 days or three weeks (Fig. G1.3.3). Another type of activity those, who already

[442] https://issuu.com/bartlettarchucl/stacks/9e12e194ae8e4ca195884c0ccb6d8d73 visited July 2019
https://issuu.com/bartlettarchucl/stacks/19e0417e5a5f4d5f8a874902fff916ca visited July 2019
[443] https://www.ucl.ac.uk/bartlett/architecture/programmes/short-courses/bartlett-summer-school-2019 visited july 2019

study architecture or related discipline, there is an intensive three-week **Summer Studio.** Participants of Summer school or Summer studio can further prolong the course with a **Weekend Portfolio Workshop**, or attend a new group activity **Maker's Week**, during which they work with the tools and machinery, and also have the introduction into render programmes, VR and film to create a design.

Fig. G1.3.3 The Bartlett Summer School

MakeLab 2011 workshop[444] (Fig.G1.3.4) took five days in Hooke Park's forrestry in April 2011, and was organised by AA Design and Make programme in collaboration with the AA Digital Prototyping Lab. The programme contained working with an experimental digital software together with constructing 1:1 structures using hardware tools and local construction material.

The course instructors were: Brendon Carlin (AADRL 2009-2011), Michael Grau (Zaha Hadid Architects), **Luke Olsen (UCL / Bartlett** and University of Nottingham and Jeroen van Ameijde (AA).

Fig. G1.3.4 Make Lab workshop

[444] http://www.s-t-x.net/?page_id=193 visited July 2019

UNIVERSITY OF BATH

The University of Bath is a public university, which can trace its roots to Merchant Venturers' Technical College established in Bristol in 1595, and a technical school established in Bristol in 1856. Together with the Bath School. It became the Bristol College of Science and Technology in 1960, and received university status in 1963 as Bath University of Technology.[445]

The university is divided into four faculties and each faculty into several departments.

The Department of architecture and Civil Engineering belongs to the Faculty of Engineering & Design.

The university of Bath currently holds **No.1 for architecture in THE complete university guide subject ranking** as well as the first position in the Times and Sunday Times Good University Guide.

The **Bachelor programme**[446] lasts 4 years, including two 6-months work placements in the second semesters of year 2 and year 3.

SE related subjects in **the first year** are: Structures 1A and Design Studio 1.1 in the first semester and Design Studio 1.2 and Detailed Design in the second semester. The outcome of **Structures 1A** (6 ECTS) course is to teach students to design a simple structure and identify and calculate the forces within it. Concepts of statics are introduced to students as well as load carrying mechanisms, sufficient for an elemntary appraisal of structures. Students also get familiar with different types of structural materials and structural assemblies. As far as the applying the principles in the context of a design problem, students learn how to analyse statically determinate structures and to estimate appropriate member sizes for premissible stress states. **Actual content of the course**: stable structures and structural mechanisms; Newon's laws; static equilibrium and free body diagrams; the concepts of forces and moments in structural members; equilibrium of loads, forces and moments in simple structures; introduction to load carrying action of trusses, beams, arches, cables and columns; the concepts of stress, section sizes and shapes; pin-jointed trusses: triangles of forces, resolving at joints and methods of sections; physical behaviour and structural form and efficiency; direct stresses and strains: Young's Modulus; beams and free body diagrams, bending moments and shear forces; bending stresses in beams, section shape and structural efficiency; web action and the concept of shear stresses; overall efficiency of beams and simple bridges,

[445] source: Wiki commons and university's website

[446] https://www.bath.ac.uk/courses/undergraduate-2018/architecture/bsc-architecture-including-placements/#course-structure visited Feb 2018

stability concepts; hanging chains and funicular shapes; simple suspension systems; three pin arches and goal-post portal frames. Apart from the lectures, there are also **laboratory demonstrations** and tutorials on structural safety (incl. examples of structural failures). Final exam counts towards 75% of the overall mark (10% class test, 15% truss design coursework).

Within **Design Studio 1.1** (12 ECTS), students are besides others introduced to materials and basic construction. The course consists of two projects: the design and construction of a sculpture on an abstract site and the design of a simple timber structure using frame construction.

During the **Design Studio 1.2** (18 ECTS) students further develop their skills, cntemplating two more projects: the design of a pavilion (single storey steel structure building with more complex brief than the previous timber structure) and the design of a house (at least two storeys, using masonry construction), when students must also demonstrate an understanding of the structural and constructional principles.

One of the aims of **Detailed Desin 1** (3 ECTS) course is getting the knowledge of the assembly of simple structures. Students get introduced to the following topics: the spirit of detailed design, basic strategies for building, floor and foundations, loadbearing structures, timber frame structures, steel structures and roof structures.

In the **second year** of their studies, there is a Structural and Detailed Design as well and Design Studio 2.1 in the first term, following by a work placement in the second term. **Structural and Detailed Design** (6 ECTS) is focused on developing an understanding of materials and building construction and on the interaction between architecture and engineering (more deatiled work in structural design). Students learn the possibilities and limitations associated with the use of various types of structural materials as well as various structural systems. Within the lectures, students get acquainted with the elements of building construction (illustarted by the extracts from construction textbooks and by the selected Case studies). A special attention is given to understandingthe process of construction as well as to analysing and understanding how the decisions are made on appropriate construction methods. Structural design process, structural materials and basic concepts of static and structural action, concepts of safety, stability and serviceability are also analysed. Students also compare efficiency and aesthetics of structures.

The majority of the **Design studio 2.1** devoted to the individual design of multi-cell building of medium complexity (non-domestic construction).

In the **third year**, there is Design studio 3.1 in the first term and another professional placement in the second term. The **Design Studio 3.1** (18 ECTS) is devoted to major more complex task (during which students **can undertake a study tour to a European city**, which becomes its setting place) as well as to a short **joint project with engineering students**.

In the **fourth year**, the main focus is given to Design Studios 4.1 and 4.2, which are awarded 18 ECTS in the first term and 30 ECTS in the second term. During the **Design Studio 4.1**, students undertake the **Basil Spence Project -** a flagship design competition, running from 1976. Students work in a small teams consisting of 2-3 architectural students and 2-3 engineering students, and the whole experience lasts approximately 8 weekd. The brief changes each year, special focus is given to sustainability, and within each project, students have to explain how the structure of their design is supposed to work. They also need to provide the calculations. The overall studies culminatein the final project work within the **Design Studio 4.2**. The students must demonstrate their ability to integrate urban, structural, constructional and environmental aspects within their design.

The **structures@bath** blog [447]was created in 2012 by the team of **Dr Evernden[448]** and **Dr Darby[449]**, and run until 2014 as a subsequent support for students to improve their structural literacy. There was a statics problem introduced each week, to which forum could take place, and results were later released by the tutors (see example in Fig. G1.4.2) as well as links to various learning resources (e.g. from the Institute of structural engineers; most still working), examples of exam papers and structural models. Twitter version is seen in Fig. G1.4.1. The structures@bath site also informes about the **computer-assisted assessment (CAA) project[450] developed and tested in 2012** in all five study programmes at the Department of Architecture and Civil Engineering of the University of Bath (including bachelor and master

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[447] http://blogs.bath.ac.uk/structures/ visited Feb 2018

[448] **Dr Mark Evernden**
senior lecturer in the Department of Architecture and Civil Engineering at university of Bath;
First Class MEng Hons degree in Civil Engineering (1998). PhD (advanced composite structures)from the University in Warwick (2006), he taught as a teaching fellow in the Department of Civil Engineering at Warwick, until 2007 teaching fellow there; teaching interests: development of key structural engineering concepts whilst advocating the appropriate use of materials; research: advanced composite materials. source: university's website, visited Feb 2018

[449] **Dr Antony Darby**
Head of Civil eng. Group at University of Bath; UK principal expert on Task Group 1 of Eurocode 2; teaches a number of Structures related units across both undergraduate and postgraduate programmes, encompassing structural analysis, structural mechanics and advanced concrete design; research interest: structural dynamics. source: university's website, visited Feb 2018

[450] EVERNDEN, DARBY, IBBEL (2013)

architectural programmes). The activity was based on blended-learning[451] approach and computer based activities. 210 core questions on the interrelation between deflected shapes, moment and shear force diagrams and equilibrium and compatibility were developed and random variations significantly increasing the question database introduced. Various types of questions were used (e.g. multiple choice, calculation based or more complex association style questions, see Fig. G1.4.3 and Fig. G1.4.4), and participating students received immediate formative feedback. Each assessment contained 8 questions to go through within 20-minutes time slot. The task was not compulsory. As an outcome, more than 1000 randomly generated assessments were completed by approximately 60% of year 1 and year 2 students. The level of participation showed lower than originally expected (cca 1.8 attempt per student), nevertheless 28% of participating students showed dedication and completed more than five cycles of self-assessment. The average success score of this group raised from 48% to 82%, showing the positive impact, which was further confirmed when semester 1 exam results of CAA participating/non-participating students were compared. Because the non-compulsory status showed inappropriate (as the students who would benefit the most did not take the part), it was dedided to make it compulsory part of the students' coursework in the next year.

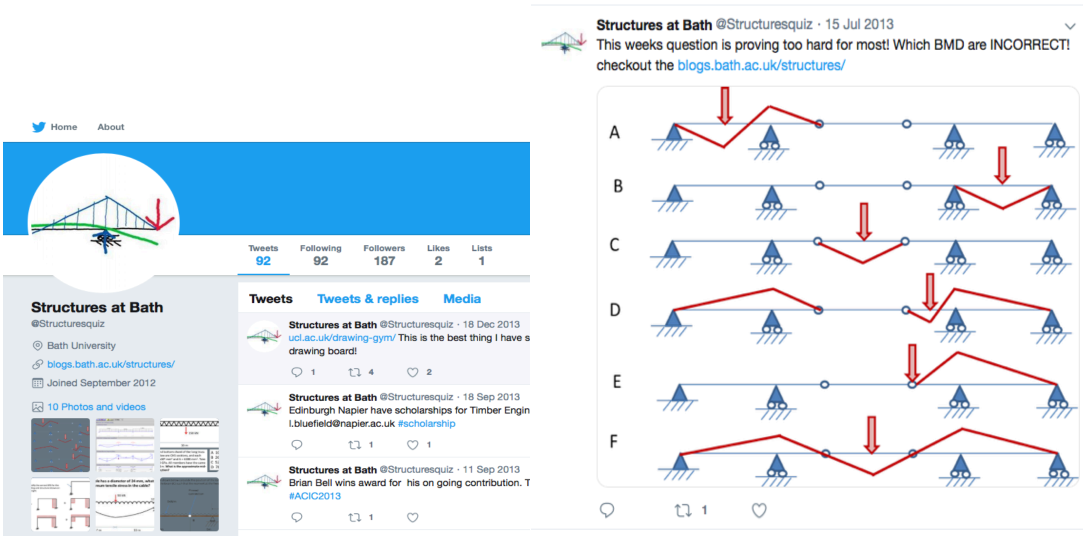
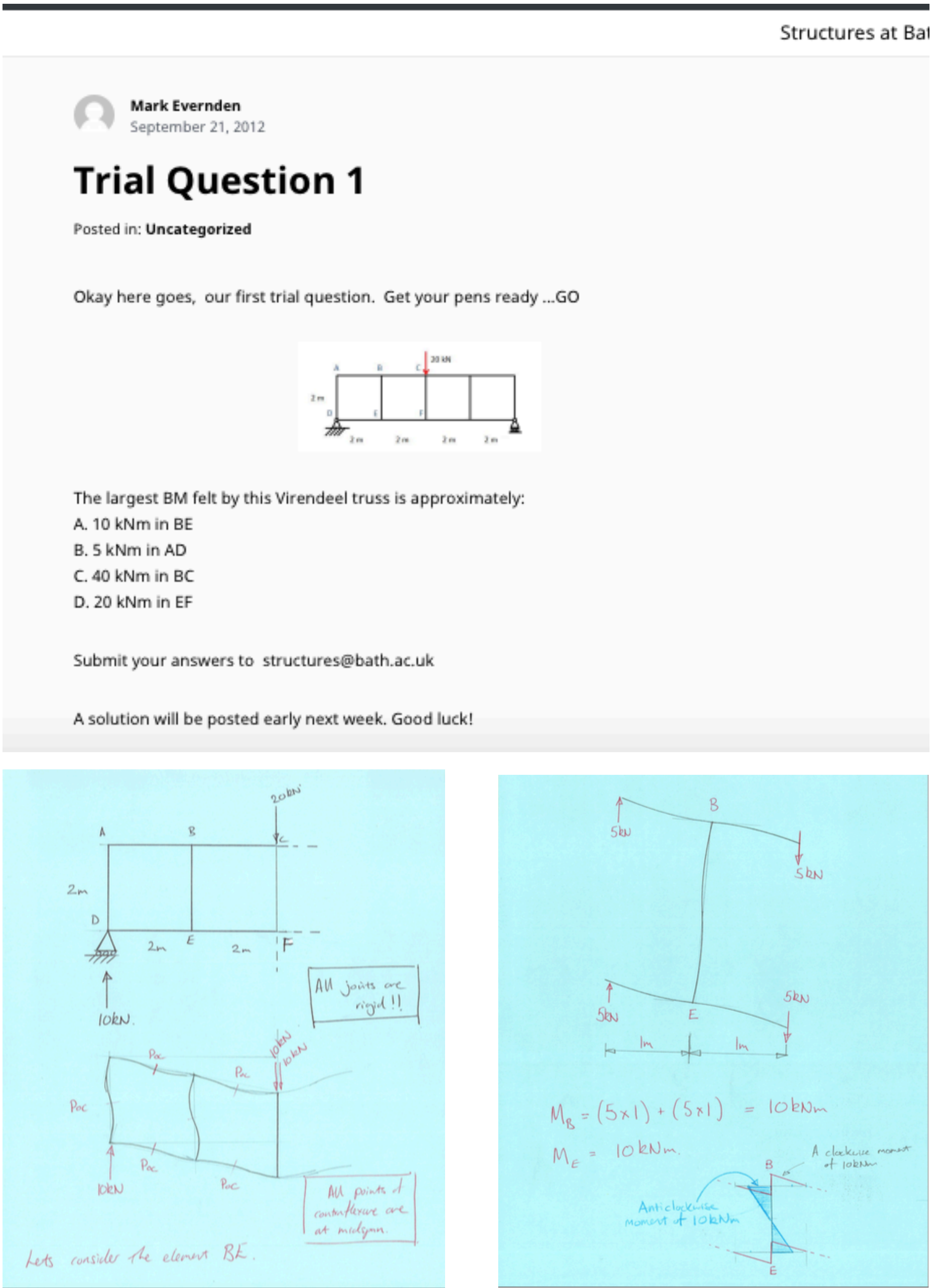


Fig. G1.4.1a,b **Structures at Bath, Twitter account**
introductory page (left)
example of a task (right)[452]

[451] Blended learning, commonly reffered as "flipping"- inverts traditional approach by delivering targeted consent outside the classroom, whilst using the face-to-face time engaging in problem solving- opens up new routes for the provision of continued individual feedback.
[452] retrieved in Feb 2018 from https://twitter.com/structuresquiz?lang=en



Structures at Bat

Mark Evernden
September 21, 2012

Trial Question 1

Posted in: **Uncategorized**

Okay here goes, our first trial question. Get your pens ready ...GO

The largest BM felt by this Virendeel truss is approximately:
A. 10 kNm in BE
B. 5 kNm in AD
C. 40 kNm in BC
D. 20 kNm in EF

Submit your answers to structures@bath.ac.uk

A solution will be posted early next week. Good luck!

Fig. G1.4.2 a-c **Structures at Bath blog**
example of a task (top)
lecturer's comment (bottom)[453]

[453] retrieved in Feb 2018 from http://blogs.bath.ac.uk/structures/

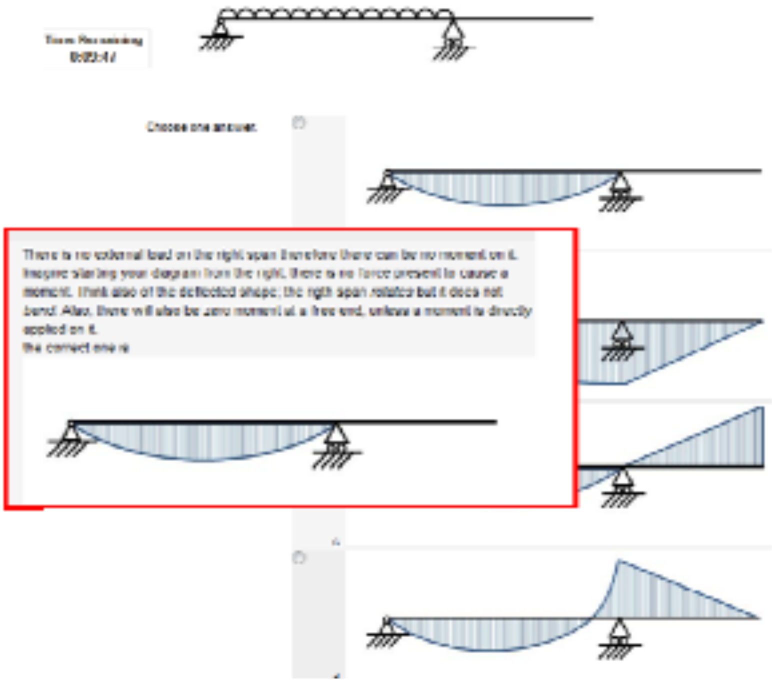


Fig. G1.4.3 **University of Bath's computer-assisted structural assessment**
Screen print of Multiple choice question displaying formative feedback[454]

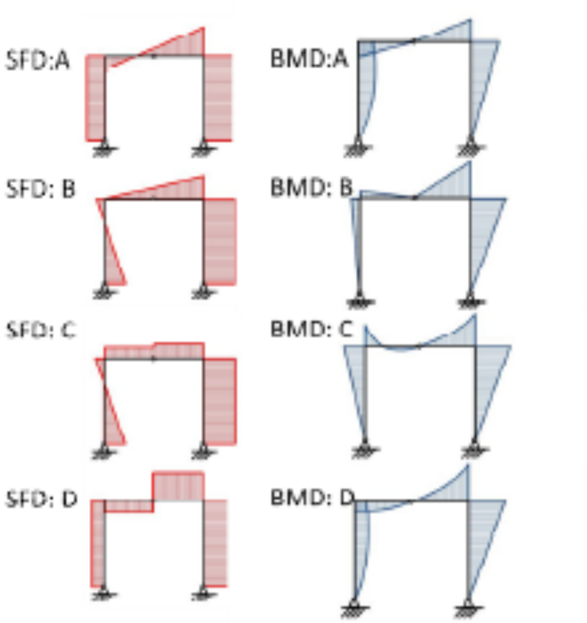


Fig. G1.4.4 **University of Bath's computer-assisted structural assessment[455]**
Association type question for shear force and bending moment relations
(Correct answer SFD:BMD, A:C, B:D, C:A, D:B)

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[454] source: EVERNDEN, DARBY, IBELL (2013)
[455] dtto

UNIVERSITY OF CAMBRIDGE, UK

Compared to continental Europe and the USA, in Britain, schools of Architecture started later. The trade was learned in offices, and only in Victorian era office assistants further supplemented their training with an evening or day-release classes. A proper system of architectural school began to form with the beginning of the new century.[456] The University of Cambridge Department of Architecture was established in 1912 and is part of the Faculty of Architecture and History of Art. It currently occupies 2nd place in the UK (both in the latest THE and QS Rankings), and is the 7th worldwide (QS Ranking). It is also interesting to notice that half of the
2019's shortlist contenders for the RIBA Stirling Prize are represented by Cambridge alumni.[457]
The department has attracted numerous guest lectures in the past, e.g. by Zaha Hadid, Alvar Aalto, Kenneth Frampton, Louis Kahn or Le Corbusier.

The Department of Architecture in Cambridge is relatively small, it has got around 120 undergraduates in 3 year groups with a ratio of 13 applicants per place in year 1, which opens 35 places for academic year 2020/21.[458] The history of the University of Cambridge dates back to the early 13th century, and many of the University's customs and unusual terminology can be traced to its earlier days; e.g. the organisation of a school year. There are currently 3 terms into which the school year is divided: **Michaelmas Term** (8 weeks from early October), **Lent Term** (8 weeks from January) and **Easter Term** (8 weeks from the end of April). With the exception of the graduate students, who attend their Studios in Easter Term, lectures are only given in the first two terms (Fig. G1.5.5 - Architectural Lectures list in academic year 2018/2019). **Bachelor Course** lasts 3 years and particular years are marked as follows: Year 1=Part IA, Year 2= Part IB, Year 3=Part II. **Master Degree** takes additional 2 years of studies.

Bachelor students are taught in **Studio two days a week**, and each of them has its own dedicated design space in there. The time allocated to studio work is set to 22-26 hours per week excluding supervision sessions (which add another 2x0.5 hours p.w. to the score)[459]. Design tutors are professional architects. Resulting studio portfolio accounts for 60% of

[456] Andrew Saint: The Cambridge School of Architecture: A Brief History
[457] https://www.arct.cam.ac.uk/news/half-of-this-year2019s-shortlist-contenders-for-the-riba-stirling-prize-are-made-up-of-cambridge-alumni , visited July 2019
[458] source: https://undergraduate.study.cam.ac.uk/courses/architecture, visited July 2019
[459] Undergraduate Handbook 2018-2019, p. 54

overall marks each year. Apart from the individual tutorials, studio work is subjected to a group critical reviews as well. In the contrast to a common practice, when students started with a smaller-scale, more abstract projects at the beginning of the course and worked towards more complex exercises at the end of the year, for the last two years the university decided to run a large scale design from the beginning, in which students cooperated in small groups whilst researching, designing and building structures for particular groups within Cambridge. For example, they have been **working with Cambridge homeless charity the Cyrenians in 2016 in order to redevelop their allotment site**, for which they have designed, planned and even build themeselves within an 8 weeks six new facilities: a tool shed with a rainwater collecting roof, a bike storage space, a market stall, a bird and bug "hotel" made from chestnut logs, a secluded area for contemplative reflexion and a social space for allotment users (see Fig. G1.5.1).

Fig. G1.5.1 year 1 students during their Studio project in 2016

Apart from Studio, first year students typically attend **six or seven lectures each week as well as three classes and three small-group supervisions** for which preparation is needed and **essays** are required to produce as an output. Regular essays and coursework in preparation for supervision and lectures do not only count towards a certain part of the final assessment (e.g. 40% weight for papers in year 1 resp. 20% weight for papers in year 2[460]), but are also an integral part of student's development and learning. The **supervision system** is an important part of the school's teaching philosophy. Supervisors are usually students'

[460] Undergraduate Handbook 2018-2019, p.49 and p.50

lecturers, with whom they meet with in small groups (2-3 people) on weekly or fortnightly basis in order to consult the work on their essays and technical coursework for the lectures. Each student has also his **Directors of Studies** appointed, with whom they meet regularly each term to consult their progress or any particular needs.

In year 1, students need to sit for 5 lecture-based papers, 2 of which are focused on structure: **Fundamental Principles of Construction** and **Fundamental Principles of Structural Design.** The rest of the papers focuses on Architectural History (2 papers) and Environmental Design (1 paper). All papers carry equal marks, assessment consists of coursework, and most papers involve a written examination component. Examinations are taken at the beginning of Easter (Summer) term and each paper takes 3 hours.

Oral examinations (viva voce examinations) might be required to be taken by students if necessary in year 3 in connection with the dissertation or any other aspects of their examination. Students present their portfolios in person to an internal examiner and then subsequently to the external examiners at the end of a year 3.

Students start to get acquainted with fundamentals of statics in the first term of the **first year** ("Autumn" Michaelmas Term) in **Structural Design** modul, which is taught by Dr. Michael Ramage[461]. The aim of the subject is to develop a sense of how structures resist forces, and to examine how materials behave under loading. Structural design and analysis is taught directly in relation to students' own work by the means of applying both numerical and graphical methods, and by reviewing built structures. The course takes part twice a week in 120 min slots., where the first hour is devoted to a lecture, followed by a 1 hour class (where content of the lecture is practically applied, e.g. some exercises are set on building structures and their testing to destruction etc.). Students are further required to allocate another 2 hours per week for a personnal study or for undertaking various assignments, also can opt for 0.5 hours of supervision time per week. The main course text is represented by ***Form and Forces*** (2009) texbook by E.Allen and W.Zalewski. Other selected readings are books: ***Structures, or, Why***

[461] **Dr. Michael Ramage**
degree in architecture from MIT; Prior to studying architecture, he had a Fulbright Fellowship to Turkey to study geology and archaeology; one of the designers of the masonry vaulting for the Mapungubwe Interpretive Centre in South Africa (won World Building of the Year award in 2009); author of the domes for the Pines Calyx (the first Guastavino-style vault to rise in the UK), and the 20-meter span vault for Crossway; recent work includes The Bowls Project at the Yerba Buena Centre for the Arts in San Francisco and The Earth Pavilion (START Festival London 2010). Source: university's website, visited Juy 2019.

things don't fall down by J.E.Gordon (1978) and ***The Masonry Arch*** (1982) by J.Heyman. Textbooks info in Fig. G1.5.2 bellow. The course is also supplemented by a field trip.

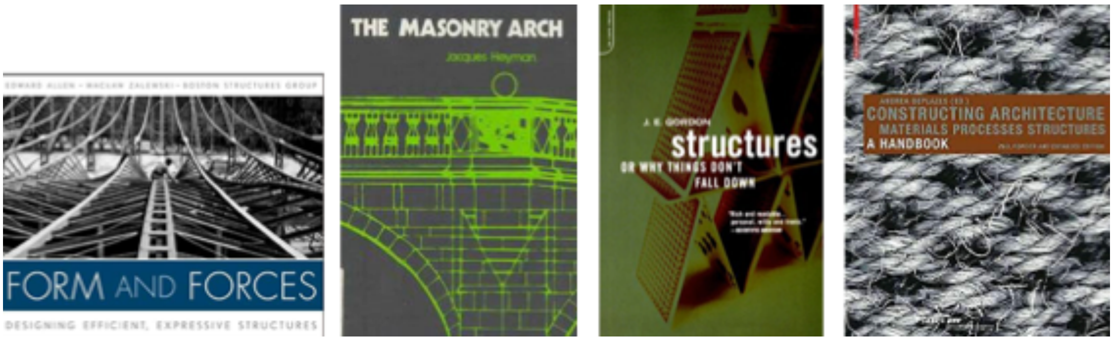

Fig. G1.5.2 (a-d) STUDY LITERATURE USED IN YEAR 1 (from left to right)
Form and Forces, ALLEN, E., ZALEWSKI, W., 2009, (a)
The Masonry Arch, HEYMAN, J., 1982, (b)
Structures, or, Why things don't fall down, GORDON, J.E., 1978, (c)
Constructing Architecture, DEPLAZES, A.ed., 2018 (4th ed.), (d)

A course on **Building Construction** in the second term of year 1 ("Spring" Lent Term) is taught by Dr. Minna Sunnika-Blank[462]. The course takes part twice a week in 120 min slots, when the first half is devoted to a lecture, which is immediately followed by a class. Students are introduced to the building site, and through site visits, lectures and coursework get acquainted with the basic understanding of **building materials** (timber, concrete, brick, metal, glass and plastics), basic construction methods and basic construction components. A small design project (integrated within the Studio programme) is included in the coursework. The main course text is represented by Andrea Deplaze's: ***Constructing Architecture: Materials, Processes and Structures*** (2008), Fig. G1.5.2d.

There is also a **compulsory 5-7 day Study Trip** abroad to an European City in Year 1 curricula, which usually takes time during an Easter break and focuses on visits and lectures on the famous building of the chosen city.

In the second year, students are split for **Studio** into 3 small groups (containing 10-15 people). There is always a shared focus of the year, which everyone follows by participating in different but parallel programmes across the UK sites. Projects may be in the form of

[462] **Dr Minna Sunnika-Blank**
is a Senior Lecturer at the Department of Architecture in Cambridge; her current research looks at energy infrastructure, gender and household practices in the context of slum rehabilitation in India; she is a Director of Studies and Fellow in Architecture at Churchill College. Source: university's website, visited Juy 2019.

mapping studies, interior design or a reasonable-sized building. As in the first year, studios take part twice a week and resulted portfolios carry 60% of the overall marks.
The second year **field trip** to a European city lasting 3-4 days takes part during Christmas holidays and is voluntary.

Structure of the papers stays the same with **5 papers per year**, 2 of which are focused on structure (**Principles of Construction** and **Principles of Structural Design**), 2 on History and Theory of Architecture and the last on Environmental Design. Marks from papers are equal and together count towards 40% of overall mark.

Second year **Building Construction** modul takes 120 min per week (1 lesson) for 2 terms (16 weeks alltogether) and is taught by Mike Driver[463]. It is in the form of a lecture accompanied by an **Examples Sheet**, which students work through in their own time. 2 hours of a self study per week is expected. They also need to produce a **construction report** on their studio work. Standard supervisions are planned twice per term, but students can book an extra ones if needed. The subject is devoted to an **external envelope** and structure in the first term, and to components and **internal finishes** in the second term. Attention is focused also towards the most common **technologies** and to the **design of a detail**. Students also get acquainted with the various regulations they need to take into account whilst working on their design. As an accompanying literature, they predominantly use ***The Architect's Pocket Book*** by A.Ross, J.Hetreed, C.Baden-Powel. As a further reading, Stephen Emmitt's ***Barry's Introduction to the Construction of Buildings*** and ***Barry's Advanced Construction of Buildings*** are recommended (see Fig. G1.5.3).

Fig. G1.5.3 a-c STUDY LITERATURE USED IN YEAR 2 (from left to right)
The Architect's Pocket Book, ROSS,A., HETREED, J., BADEN-POWEL, C., 2017 (5th ed.)
Barry's Introduction to the Construction of Buildings, EMMIT, S., 2018 (4th ed.)
Barry's Advanced Construction of Buildings, EMMIT, S., 2018 (4th ed.)

[463] **Mike Driver** (MA DipArch RIBA)
is a member of Christ's College and Affiliated Lecturer in the Department of Architecture where he specialises in Construction and Design. Source: university's website, visited July 2019.

Second year subject **Structural Design** takes also 120 min per week (1 lesson) for 2 terms (16 weeks alltogether) and is taught by Dr.Emily So[464]. Students are introduced to more complex tasks from the structural design with the emphasis on **concrete and steel** structures. The course is fulfilled by the lectures, classroom sessions and in cooperation with the Design Studio, students must produce a **structural investigation of a design project**. Their final portfolio must include technical sheets on the structure. Required self study is 2 hours per week, supervisions are on request and count towards 0.5 hours per week.

The course text is represented by D. Seward's ***Understanding Structures: Analysis, Materials and Design***, recommended for further reading are: ***Structural Engineer's Pocket Book*** by F.Cobb and ***Structure and Architecture*** by authors Salvadori & Heller (Fig. G1.5.4).

Fig. G1.5.4 a-d Study literature used in year 2 (from left to right)
Understanding Structures: Analysis, Materials and Design, SEWARD, D., 2014 (5th ed.)
Structural Engineer's Pocket Book, COBB, F., 2014 (3rd ed.)
Structure and Architecture, SALVADORI, M.G., HELLER, (5th ed. 2018, 4th ed. 2016)

Students typically have lecture on each subject every week. For additional **weekly supervisions** by subject lecturers they need to produce **essays** and carry out basic preparation.

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[464] **Dr Emily. So**
is a chartered civil engineer and a Reader at the Department of Architecture; Director of Studies and Fellow in Architecture at Magdalene College and a Director of Cambridge Architectural Research Ltd.; before worked at Arup as a senior geotechnical engineer;
her area of specialty is casualty estimation in earthquake loss modelling; has been involved in interdisciplinary and international collaboration through her work with the UK Earthquake Field Investigation Team (EEFIT) and the Global Earthquake Model (GEM); the 2010 Shah Family Innovation Prize winner. Source: university's website, visited July 2019.

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The **Studio in the third year** of studies must result in producing a project of a "quite large" building", which demonstrates mastering both theoretical and technical aspects of architectural design. Time tabling stays twice a week as well as 60% weight to the portfolio.

There are **4 papers** in the third year: Advanced studies in historical and theoretical aspects of architecture and urbanism, Management, Practice and Law, **Advanced Studies in Construction Technology, Structural Analysis and Environmental Design Related to Case studies** and the paper from **Architectural Engineering**. Apart from these, they need to submit a 7,000-9,000 word **Dissertation**.

Architectural Engineering Course takes part in Michaelmas Term. It lasts 180 min per week (1 lesson) and requires additional 3 hours of personal study per week. The course co-ordinator is Dr. Ramage[465]. The course is organised **jointly with the Engineering Department,** the third year architecture students work in mixed teams of 4-6 people with the fourth year engineering students. The course is wholly marked on the coursework and contains both group and individual work. Engineering and architecture students are marked separately on their individual work.

The aim of the course is to get used to a cooperation between an engineer and an architect. Engineering students bring "objective"(technical) aspects of structure into view, whilst architectural students promote their "subjective" (design) views - together they need to find a suitable balance for their design. The final project must contain appropriate calculations for light, sound, energy, heat and structure.

Advanced Studies in Construction Technology takes 180 min per week (1 lesson) and is taught by A.Short[466]. During the Lent term, students take regular visits to two buildings currently under development and also attend lectures given by members of the design teams, who work on these buildings. They need to submit a case study notebook at the end of the term, which counts towards their grade.

As specified in the Undergraduate Handbook, there are currently several Departmental Prizes, one of which is the **Prior Prize in the third year** awarded to the student whose drawings

[465] **Dr Michael Ramage**, see fn 461

[466] **Prof. Alan Short**
educated at Trinity College and as Exchange Fellow at Harvard University's Graduate School of Design; Professor of Architecture at the University of Cambridge since 2001; focuses on the design of sustainable buildings; PR China Ministry of Education Distinguished Professor, a Guest Professor at Zhejiang University; was the 2014 George Collins Fellow of the Society of Architectural Historians and 2013-14 Geddes Fellow at the University of Edinburgh; also designs buildings and is deeply involved in Higher Education and Research;holds many RIBA awards. Source: university's website, visited Juy 2019.

display the **best understanding of building construction** and use of materials. The actual amount of money varies, usually is around GBP 300.[467]

The **Summer School** programme runs for the potential study candidates each year.[468]

OFFICIAL LECTURE LIST

Lectures Proposed by the Faculty of Architecture and History of Art

ARCHITECTURE TRIPOS

MICHAELMAS TERM 2018	LENT TERM 2019

PART IA

MICHAELMAS TERM 2018	LENT TERM 2019
Paper 1: Introduction to History and Theory of Architecture before 1800 PROF. W. PULLAN (week 1, 5 Oct) F. 11-1 MS S. SINGLER (weeks 2-8, 12 Oct- 23 Oct) F. 11-1	***Paper 1: History and Theory of Architecture before 1800*** PROF. HOWARD (weeks 1-4, 18 Jan- 8 Feb) F. 11-1 PROF. C. VAN ECK (week 5, 15 Feb) F. 11-1 DR F. SALMON (weeks 6-8, 22 Feb- 8 Mar) F. 11-1
Paper 2: Introduction to History and Theory of Architecture after 1800 DR F. HERNANDEZ (weeks 1-8, 10 Oct- 28 Nov) W. 9-11	***Paper 2: Introduction to History and Theory of Architecture after 1800*** The same continued (weeks 1-8, 23 Jan -13 Mar) W. 9-11
Paper 4: Fundamental Principles of Structural Design DR M. RAMAGE (weeks 1-8, 5 Oct- 27 Nov) Tu. 9-11 & F. 9-11	***Paper 3: Fundamental Principles of Construction*** DR M. SUNIKKA-BLANK (weeks 1-8, 18 Jan- 12 Mar) Tu. 9-11 & F. 9-11
Paper 5: Fundamental Principles of Environmental Design MS M. STEANE & OTHERS (weeks 1-8, 10 Oct- 28 Nov) W. 11-1	***Paper 5: Fundamental Principles of Environmental Design*** The same continued (weeks 1-8, 23 Jan- 13 Mar) W. 11-1

Fig. G1.5.5 Architectural Lectures list in academic year 2018/2019[469]

467 Undergraduate Handbook 2018-2019, p. 104

468 https://www.immerse.education/our-programmes/cambridge-architecture-summer-school-16-18/ , visited July 2019

469 retrieved July 2019 from https://undergraduate.study.cam.ac.uk/courses/architecture

UNIVERSITY OF EDINBURGH, UK

The Edinburgh School of Architecture and Landscape Architecture (ESALA) is part of Edinburgh College of Art at the University of Edinburgh, Scotland. Edinburgh College of Art was established in 1907, and the first architecture courses were atught in 1908. Currently offered courses are on Architecture, Architectural History and Heritage, and Landscape Architecture.[470]

All students are admitted to MA programme and at the end of Year 2 they can decide whether to opt for three-year BA, or 4-year MA programme (where also an option for 1 year exchange study abroad is available). The university also offer a 3 or 4 years course Structural Engineering with Architecture (BEng or MEng) provided by College of Science and Engineering.
There are four teaching blocks during the academic year in total of 20 weeks plus 2 revision weeks, therefore each term consists of 11 weeks teaching time (from mid September to December and from mid January to April).

Lets have a look at **Bachelor/Master of Architecture** courses first:
In **year 1,** students have 3 courses each term, awarded equally 10 ECTS credits each.
They learn about principles of architectural design (work on projects that look at architectural elements in the first term resp. and on an assembly in the second term), about architectural history and are taught the fundamentals of technology in a course **Technology and Environment: Principles**, is taught by **Elaine Pieczonka** and takes place in the second term.

There is 1 lecture and 2 seminars per week, each lasting 50 minutes. Total number of students in a yeargroup is around 120, for seminars, they are split into groups of 20-25 students. Independent learning is estimated to 125 hours net time per term. Written exam at the end of a term takes 1 hour and its weight toward overall mark is 25%. Coursework (written reports) is responsible for 75% of the overall mark. Students are offered online practice exam questions.
At the end of the course students should be able to: demonstrate knowledge and undestanding of the principles of architectural structures , and understand key concepts in their physical behaviour together with the knowledge on the propertis of various types of material. They should be able to apply this knowledge to in their project work.

[470] source: Wiki commons

Essential reading for the course is represented by the following texts: (Fig. G1.6.1).

Fig. G1.6.1a-d ***Structural Engineering for Architects,*** SILVER,P., McLEAN, W., EVANS, P., 2014
***Introduction to Architectural* Technology**, SILVER,P., McLEAN, W., WHITSETT, D., 2013
Constructing Architecture: Materials, Structures, Processes, DEPLAZES, A., 2018 (4th ed.)
The Architect's Pocket Book, ROSS,A., HETREED, J., BADEN-POWEL, C., 2017 (5th ed.)

There is also a suggested reading as seen below: (Fig. G1.6.2)

Fig. G1.6.2a-h ***Structure and Architecture***, MacDONALD, A.J., 2018 (3rd ed.)
Building Construction Illustrated, CHING, F.D.K., 2014 (5th ed.)
Building Construction Handbook, CHUDLEY, R., GREENO, R., 2016 (11th ed.)
Architecture In Detail, BIZLEY, G., 2007 (VOL I) and 2010 (VOL II)
Tony Hunt's Structures Notebook, HUNT, T., 2003
Design-Tech: Building Science for Architects, ALREAD, J., LESLIE, T., 2014
Materials for Architectural Design, BALLARD BELL,V., RAND, P., 2005

Year 2 is organised analogically with 3 courses each term (equally awarded 10 ECTS credits each), but project challenges students with more complex urban context and more ambitious building programme briefs. It includes a field trip to a European city, where design project are situated. "Technologies" are an important part of a curricula, and are taught both in the first and second term. There is a **Technology and Environment 2A part: Building Environment** (climate, energy consumption, landscape principles, materials sourcing, dayligh, sunlight, artificial light, acoustics, ventilation, thermal control) taught by **Elaine Pieczonka and 2B part: Building Fabric** [471] taught by **Dr. D. Theodossopoulos**. Urbanism is also taught in Year 2 as well as 1 selective subject.

Building Fabric course focuses on application of the structural principles learned in the previous term to a design of a medium-sized buildings. Process of dimensioning structural elements, structural stability and serviceability in structures are explored for the main structural materials (concrete, timber, steel) . The course consists of lectures (2 teaching units in the total time of 110 min per week) and exercises (50 min per week). The topics of particular lectures are as follows: Structural Loads, Structural Analysis (Stress, Stiffness, Qualitative Analysis), Materials (Technologies and Properties of Steel, Concrete and Timber), Sizing of Timber Structures, Design in Frame Structures, Connections, Soils and Foundations, Ligh Envelope (Principles and Technology), Stone Cladding, Roofs, Masonry and Cellular Structures[472]. There is also a case study guest lecture and several project tutorials during the term. Independent learning at home should take around further 150 hours per term. There is no written exam, the course is assessed entirely on coursework, where 25% is awarded to each of two Assignments, and 50% alltogether is shared between 3 short Essays on following topics: Materials, Super Structure and Envelopes (700 words, 3 pages and 5 illustrations). See Fig. G1.6.4 and Fig G1.6.5a-d for the illustration of the assigned course work.

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[471] **Building Fabric** refers to structural materials, cladding, insulation, finishes etc. that enclose the interior of a building separating the internal from the external. Very broadly, for most buildings, the building fabric will include a number of elements such us the roof, external walls, doors, windows, and the lowest floor)
Source: design buildings wiki website, visited June 2018.

[472] **Cellular Construction System** is a construction system that is adopted from the cellular structure of the human body. Instead of using the conventional rigid construction methods, we divide buildings into independent construction cells that are connected together via nodes to form the complete structure. Our system results in stronger building that can better sustain earthquakes, wind and other natural forces, in addition to being more flexible allowing for new designs not possible using current methods. Our initial analysis also revealed substantial cost savings (20-30%) and time savings (50%) compared to other well used systems.
Source: IFIA website, visited June 2018.

As an **example of 2018 projects**, there was a task of designing a **single tier exposed timber walkway for Dirleton castle**, which would move round the ruined walls and provide a safe platform for visiting the whole site as well as incorporating a viewing platform. Specific site conditions had to be taken into account. As a part of their project, students had to calculate section sizes for beams and columns according to a EC5 Eurocodes, design suitable connection details and explain the method by which is the load transferred through the connections. Showing the difference for analysing the beams and columns as a part of a frame vs. simply supported spans. A support of the walkway had to be also designed and its most loaded column calculated. Students worked in a group of 4, the group work was therefore alternated with an individual during the task.

As a **second project task**, students had to design **a pavilion** at the same venue, which would work as an educationnal area with possibility of hosting temporary exhibitions and similar events. Capacity of the pavilion would be for 30 people. As before, the students worked both in a group and individually. They had to incorporate the previous task into the whole scheme, new assignment include solving pavilion's envelope and roof construction. Timber or steel frame was suggested to use, foundation pad to transfer the load from the pavilion to the ruins had to be designed. A proper support for cladding and the roof was also requested to produce, although beams, columns and rafters need not to be sized. Connection details had to be proposed for important parts of a structure.

For the **first essay**, a medium sized building (up to 5 storeys high) was given for analysis on material variations of its main load-bearing structure and its envelope. Properties of a different material solutions had to be discussed together with highlighting its pros and cons. Relevant case study for each system was requested to comment upon.

As far as the **second essay** is concerned, 5-storey residential building steel frame had to be designed to withold the effects of typical structural loads (dead load, imposed load, wind, fire). Strategy for stability and stiffness had to be reviewed together with connections design, and other aspects of the structure.

Finally, for the **third essay,** an analysis of solid envelopes build either with large square stones or by using concrete frame was given to produce. Diagrams and case studies were requested to use in order to illustrate the study.

The study literature for the course is shown in Fig. G1.6.3.

Fig. G1.6.3a-g ***Building Construction Illustrated***, CHING, F.D.K., 2014 (5th ed.)
Structures textbook, SCHODEK, D., BECHTHOLD, M., 2013 (7th ed.)
Building Structures from concepts to design, MILLAIS, 2005 (2nd ed.)
Timber Construction Manual, HERZOG, T., NATTERER, J. et al., (2004)
Constructing Architecture: Materials, Structures, Processes, DEPLAZES, A., 2018 (4 th ed.)
Building Skins, SCHITTICH, C., 2006 (2nd ed.)
Facade Construction Manual, HERZOG, T., 2018 (2nd ed.)

Design in **Year 3** is studied in cultural and technical contexts. Architectural theory and Design are awarded 30 ECTS credits in total and are taken during the first term, professional practice is awarded 30 ECTS credits and takes time during the whole year. Students of MA course may opt for a year abroad studies at a partner institution, provided they fulfill an equivalent of 40 ECTS credits for a Design Studio in there.

Year 4 is intended for Master students only, who need to work on their Dissertation in the first term (20 ECTS credits), and attend following subjects in the second term: Architectural Design: Tectonics (10 ECTS), Architectural design: Logistics (5 ECTS), Academic Portfolio (5 ECTS). Selective course complement the study plan with 10 ECTS. There is a Technology 3 course on offer as well as a course on Structure and Architecture.

Students are educated in the form of lectures, seminars, studio based projects, critical reviews, practical experience and field trips. They are assesed by exams, coursework, presentations and portfolio work. Dissertation is part of a 4 year MA study.

ESALA

Edinburgh School of Architecture & Landscape Architecture

TECHNOLOGY & ENVIRONMENT 2B:
BUILDING FABRIC
Academic Session 2017-18
Course Code: ARCH08027

Assessment for Learning Outcome 3

LO3: Understand the range of applications of the principles of assembly and structural performance with regards to the main material systems (masonry, timber, steel and concrete) in the design of medium-sized buildings.

The intention of this coursework is to encourage you to review and reflect consistently on the lectures material throughout the semester by working on 3 short essays of equal weight on key themes of the course. This replaces the end of semester examination. It will also provide formative and summative assessment through the semester. It is important that you show engagement with the core content of the lectures and show some reading beyond the core material. You do not need to include a references list, but please remember that Turnitin can check the originality of your work.

This is a short essay and should be approximately 700 words, 3 pages and 5 illustrations. The latter can be technical diagrams (drawn by hand or software) or photos (can be annotated) and refer to the design of contemporary case studies where appropriate, either from the lectures or architectural literature.

Feedback will be given on the quality and depth of your answer, but also your skills in reporting a technical subject.

Essay 2: Super/ substructure (Week 8)

Based on the effect of typical structural loads like dead load, imposed loads, wind action and fire, discuss how the typical structural layout for a 5-storey residential **steel frame** building can be designed to resist such loads. Discuss the strategy for stability and stiffness, the design of connections, the construction sequence and a typical resulting layout for this type of the structure. Use diagrams and case studies to illustrate your answer. Identify a key priority of the design of the case studies and be critical on why this particular technique or strategy was used against another.

Upload your essays to the Turnitin submission box as a single, typed document by 12.00 hours on Monday 26 March 2018.

Fig. G1.6.4 Assignment of an Essay from TE subject in year 2 (academic year 2017/2018)[473]

[473] received in June 2018 / materials of Dr. Theodossopoulos

ESALA

TECHNOLOGY + ENVIRONMENT 2B. BUILDING FABRIC

Semester 2, 2017-18

RESTORING DIRLETON CASTLE

Dirleton Castle served for 400 years as the power centre for the de Vaux, Haliburton and Ruthven families. The castle became obsolete after the downfall of the Ruthvens and Cromwell's siege in 1650. Even in this state, Dirleton conveys today the juxtaposition of phases, the ambitions of the owners, the need to combine defence and comfort, and the achievements of stone masons in creating imposing spaces.

From 1356, after the Wars of Independence, John Haliburton rebuilt the castle, adding a new residential tower and a great hall along the E side of the courtyard. You are asked to design a lightweight timber structure that includes a viewing walkway and a pavilion on the North end to recreate portions of the Great Hall area and the Dais Chamber, and "stitch" visually the medieval past of the castle, restoring the original impression of the volume of the area. In this project, you will dimension the walkway and provide only a general design for the North pavilion, which will be resolved in its envelope and roof construction as the second project of this course.

DESIGN OF THE WALKWAY

The walkway can be considered as a "new wall" that moves around any of the ruined walls, over viewing the courtyard to the West or the East wall, even recreating the scale of the enclosure. Essentially a footbridge/ walkway on supports of heights of your choice, the location and layout of the boardwalk (linear or curved in plan) should be chosen to allow comfortable access to visitors and to provide a new narrative for the castle, through either volumetric recreation and its relationship to the ruins or views to the castle and the area. The form should not be overwhelming and the materials (timber, connections, ancillary elements) should be sympathetic to the character of the stone masonry of the castle and the existing timber works, as also durable and safe.

Fig. G1.6.5a Project Assignment from TE subject in year 2 (academic year 2017/2018), p.1/4[474]

[474] received in June 2018 / materials of Dr. Theodossopoulos

You will design and dimension a single tier walkway in exposed timber construction that can carry loads from pedestrians. The platform must be constructed with care for its durability and location. In order to highlight the complexities of building in an archaeological site, assume supports that cause minimum disturbance and determine the key stages in the installation process of the structure.

TIMETABLE

Handout:	Tuesday 23 January 2018 (W2)
Tutorial 1:	Week 4 (Monday 5 February and Tuesday 6 February) at Dimitris' office and Studio Q in Hunter Bldg – see sign-up sheets
Tutorial 2:	Week 5 (Monday 12 February and Tuesday 13 February) at Dimitris' office and Studio Q in Hunter Bldg – see sign-up sheets
Submission:	Thursday 1 March, 12. noon (Week 7). Please hand one hard copy at the UG Office in Minto House and upload on Learn
Feedback:	Uploaded in Learn in Week 9. Feedback session on Tuesday 20 March

SPECIFIC SITE CONDITIONS

1. **Ground:** the existing structures (ruins) are strong enough to withstand additional loads from the walkway columns.
2. The posts should be a minimum 3m high from the current level.
3. **Layout of the walkway:** it can follow any pattern through the area, not necessary along the walls footprint, but respect and enhance visitor access.
4. **Timber:** All timber used must be of standard solid sections (softwood or hardwood). Glu-laminated timber is **not** allowed.
5. **Environmental conditions:** the timber should be durable for the exposed location (wind and rain). Metal connections should be protected against corrosion.

PROJECT REQUIREMENTS

1. **Layout:** Prepare a plan showing the position of the walkway over the Hall and the layout (columns, primary and secondary elements). You must ensure adequate access to the platform. The new structure must be minimum 20 m long (one side) and 2m wide. It should be an addition to the castle and improve its appreciation, but should not restrict the views and contact with the authentic fabric.
2. The finished **timber structure** will be exposed and you must select an appropriate species of timber, taking account of appearance, strength and availability. The use of Scottish hardwoods as the main structural material is encouraged, so explore its aesthetic potential.
3. **Member sizing:** Calculate the section sizes for the beams and columns. Use the process according to the Eurocode EC5 described in the lectures and examples. Standard sizes for floor decking are given below.
4. **Joints:** Design suitable details for the beam to column connections, or beams to cross-bearers. Indicate the size and type of connectors chosen. The method by which the load is transferred through the connection (pin or fixed) should be highlighted according to its role.
5. **Support of the walkway:** design a support/ foundation pad to receive the load from the worst loaded column. The pad should be independent from the fabric and removable in case the whole walkway has to be taken down.

DESIGN PROCESS

You will work in **groups of four** and there is a mixture of group and individual work.

- At initial design stage, develop the layout considering strategies for in-plane stability (choice of ties or fixed joints) and robustness (progressive collapse)
- Using the process from EC5, size the beams and columns, considering the worst possible loaded bay under a combination of the **UDL** from the dead and imposed

2

Fig. G1.6.5b Project Assignment from TE subject in year 2 (academic year 2017/2018), p.2/4[475]

[475] received in June 2018 / materials of Dr. Theodossopoulos

load and a high **point load (4.5 kN)** that represents light pedestrian traffic, at the middle of the most critical bay. Show the difference when the beams and columns are analysed as part of a frame or simply supported spans.

SUBMISSION REQUIREMENTS

The submission should be a report in A3 format, divided between group-work parts and individually elaborated ones. The **group-work** will be 50% of the mark and will include:

1. **Justification of the design:** statement on the design and explanation of the reasons for selection, including description of the timber used and species, use of precedents, initial sizes and layouts.
2. **Layout drawings:** carefully annotated drawings in 1/100 showing the plan layout of the platform, including columns, primary and secondary beams and decking.
3. **Sections drawings:** 1/20 through the platform.
4. **A discussion of the design** in the initial stage.

Individual work: Each part is equally weighted and counts for the rest 50%. The submission MUST indicate the group member responsible. The calculations or detailing part can be done by two students.

1. Schedule of **calculations** to demonstrate the selection of the timber, verify the appropriate size of structural elements and show how you can make non-invasive supports of the columns. This should be preceded by qualitative planning at initial design (stability, robustness). To calculate bending moments and forces you can use the process in the handouts or the Framework/ Easy Statics programs. The foundation pad will be sized according to a process shown at Week 7 lectures.
2. **Detail drawings** at 1/5 showing typical connection details. These drawings should clearly demonstrate the methods of load transfer and assembly, as well as the type and size of connectors used. They should include the attachment of the primary and secondary beams to the columns, as also the connection to the foundation pad and its layout. Include only a sketch for balustrade/ stairs detail.
3. An **axonometric drawing** illustrating the platform and the space in relationship to the castle or the area in particular.

KEY DEVELOPMENT STAGES (see separate handouts)

Tutorial 1

- Familiarisation with site
- Initial design of a plan
- Discussion of case studies (load-bearing scheme, relationship to landscape, choice of timber)
- Clarification of sizing process and initial structural layout

Tutorial 2 (see separate handout)

- Finalisation of structural design
- Production of calculations and preliminary sizes
- Architectural character of proposal (architecture of timber)
- Plan construction strategy and design of key details

DESIGN PARAMETERS

The **design loads** are as follows (no lateral (wind), vibration or impact loads).

Imposed load	5.0 kN/m^2	UDL
Dead load	0.5 kN/m^2	UDL
Point load	4.5 kN	at the middle of the most critical bay

Max spans of various types of **floor decking** for an imposed load of up to 5.0 kN/m^2 (NAFI Datafile SS4)

3

Fig. G1.6.5c Project Assignment from TE subject in year 2 (academic year 2017/2018), p.3/4[476]

[476] received in June 2018 / materials of Dr. Theodossopoulos

	Size W x t (mm)	span (mm)
Hardwood unseasoned	70 x 45	660
	120 x 45	1060
	145 x 45	1200
Hardwood seasoned	70 x 45	916
	120 x 45	1199
Softwood seasoned	70 x 45	371
	120 x 45	639

LEARNING OUTCOMES

LO1 On successful completion of this course, you will be able to apply the mechanisms of design of structures that address increasingly complex interactions between forms, human use and the environment of a site, in terms of imposed actions and the impact of the chosen material

REFERENCE MATERIAL

Dirleton Castle: http://canmore.rcahms.gov.uk/en/site/56735/details/dirleton+castle/
http://www.historic-scotland.gov.uk/index/places/propertyresults/propertyoverview.htm?PropID=PL_089
Original plans and bigger size aerial photos from Canmore can be viewed at the National Monuments Record http://www.rcahms.gov.uk/visit-our-search-room.html
Stone in Dirleton:
http://www.bgs.ac.uk/data/britrocks/britrocks.cfc?method=listResults&pageSize=20&registrationNo=&rockName=&locality=Dirleton&collector=

- Learn: Project folder contains scale maps of the area and photos
- Choice of timbers: database www.trada.co.uk
- Scottish Hardwoods: www.ashs.co.uk
- Manual for the design of timber building structures to Eurocode 5. The Institution of Structural Engineers and TRADA. December 2007.
- Easy Statics: http://easystatics.ethz.ch/AboutEasyStatics/E/install.htm
- Framework 2 (free structural analysis program) http://members.ziggo.nl/wolsink/

- Timber in Construction, TRADA
- Timber Construction Manual, Herzog, Natterer, Schweitzer, Volz and Winter
- Working Details, AJ, vol.213, No.3, pp36 – 37, 25th Jan. 2001
- New timber architecture in Scotland, P. Wilson, Arcamedia 2007
- Timber Decks: Commercial, Industrial & Marine. NAFI Timber Manual Datafile SS4
- G. Carbonara, 2008. Atlante di restauro. UTET (quality case studies)

Initial precedents
- Footbridges in Figgate Park, Edinburgh; Newbattle Abbey (see Learn folder): timber and durability
- Visitor Gateway Building, Royal Botanic Garden Edinburgh: connections
- Strathnairn Woodland Shelter: simple exposed frame in Scottish hardwood
- Domus Fregellae (Italy), Koldinghus (Denmark), Casa del Condestable, Pamplona (Spain), Ravenna Castle (Italy), Dundonald Castle (Dumfries), Vindolanda (Hadrian's Wall): timber and ancient ruins

Dimitris Theodossopoulos
January 2018

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Fig. G1.6.5d Project Assignment from TE subject in year 2 (academic year 2017/2018), p.4/4[477]

[477] received in June 2018 / materials of Dr. Theodossopoulos

UNIVERSITY OF MANCHESTER, UK

Manchester school of Architecture has been educated architects for more than 100 years. It was ranked **No.3 in the UK in QS 2019 Worlds University Ranking by subject**. The bachelor architectural course (B.A.) takes 3 years, and is taught in colaboration between two campuses: University of Manchester and Manchester Metropolitan University. The learning takes place in the form of tradictional lectures, workshop and design studio sessions. The basis of architectural education is a project-based learning. the course has strong links with architectural practices across the North West. Students are assessed by project reviews, assignments, essays and online assessments. There are 4 study blocks (of equal study weight) in each year curriculum: 2 studios, humanities group and technologies group. Master studies take additional year, or 2 years when combined with urbanism.

Seeing and Touching Structural Concepts

Dr. Tianjian Ji and Dr. Adrian Bell, both senior lecturers at School of Mechanical, Aerospace and Civil Engineering at University of Manchester have created in cooperation with students an interesting and educatively benefitial website devoted to explaining principles of statics and dynamics "Seeing and Touching Structural Concepts". The work on the concept began in 1999, the exact website was first launched in 2006, and updated in 2009. The project was further financially supported by various organisations outside the university (e.g. by The Education Trust of the Institution of Structural Engineers), and the authors got an award for Excellence in Structural Engineering Education from the British Institution of Structural Engineers in 2014. Despite being developed at the Civil Engineering division, the product is recommended for general use of structural engineering lecturers across the various professional fields, including architectural education and praxis. The project is available online, and there is also an accompanying updated second edition textbook, which was published in 2015. Fig. G1.7.1. The book contains over 60 sets of physical models photographed in different stages of action in order to demonstrate basic structural principles. Each case is also further illustrated with the real life examples.

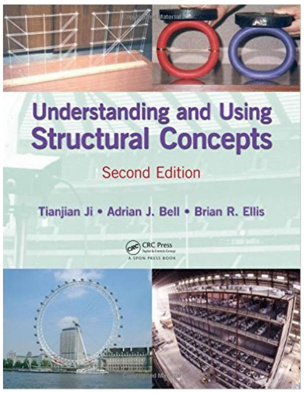

Fig. G1.7.1 ***Understanding and Using Structural Concepts***, JI, T., BELL, J. et al., 2015 (2nd ed.)

The motivation behind the project was authors's ambition to initiate a type of coursework, which would meet following requirements: to stimulate student's interest in their own learning, to make learning lecturing structural concepts more effective, to strengthten the comprehension of structural principles and invigorate the ability to apply them inovativelly. They wanted involve students in hands-on activity, which would lead to improve an ability of finding a practical solution for a real-life structural problems. [478] Initially, they have chosen year three students (90 people), because they wanted to involve students that have already been taught some principles, and later on broadened their selection to master students as well. They assumed, that students' level of understanding structural principles varies, and that they know little about applying these principles in praxis. The course was accompanied by four lectures. In the first one, rules for designing stiffer structures were explained, the second one was devoted to introducing the website (demonstration how it works, explaining the concept). Then, students had to go through the website,[479] containing following sections for each particular topic: Definition, Model Demonstration, Practical Examples and References (see Fig.G1.7.4a-d). It represented a quick revision together with enhancing the current knowledge (through the sections Model Demonstrations and Practical Examples). The third lecture was dedicated to the exact assignment, demonstrations of examples (in later stages previous students' work), and students were let to think the project over. They had to either design a physical model that would be able to demonstrate one structural concept or identify and describe an example from everyday life, which demonstrates creative grasping of one structural concept. The required volume consisted of 2 pages only, as the tutors wanted students to concentrate on the content (see Fig.G1.7.2.).

[478] Ji, T., Bell, A.: ***Enhancing the learning of structural concepts through using a website and Blackboard****,* *2009*
[479] http://epsassets.manchester.ac.uk/structural-concepts/ , visited July 2019

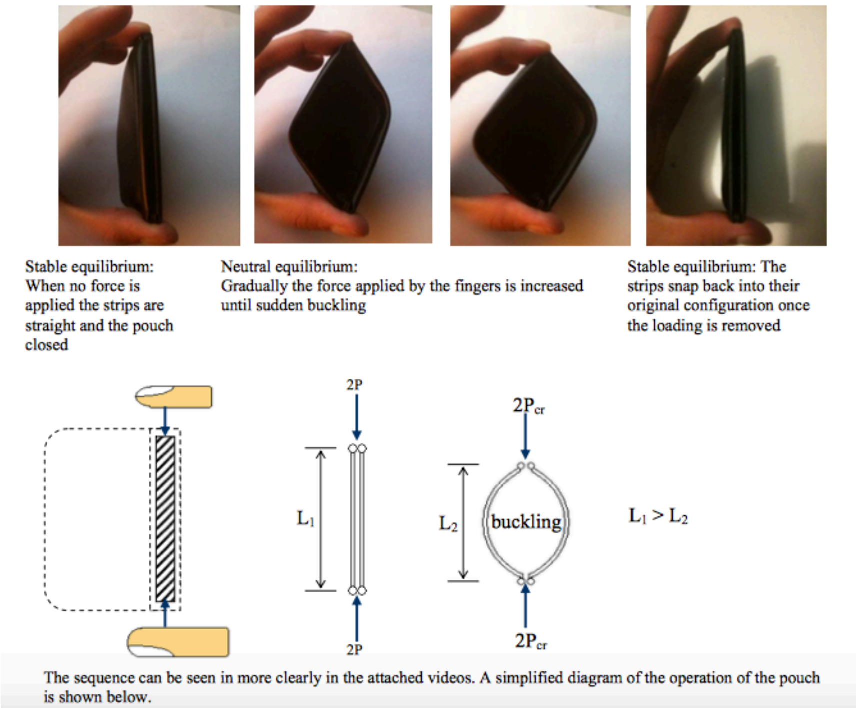

Fig. G1.7.2 example of student's work
Using global buckling to open an earphone carry pouch by Omar Farooq
source: ***Understanding and Using Structural Concepts***, JI, T., BELL, J. et al., 2015 (2nd ed.)

Cost of material needed for the project were met by university, students could discuss their ideas with tutors and use school's facilities and any special equipment they needed as well as staff assistance. At the last lecture, there was a summary of submissions, general feedback, highlighted good examples and given cash prizes to three projects with most votes (students downloaded project to a special website, where the other partipcipants could see it and each student had to cast his votes for the three best works (could not vote for himself)). The students works were later compiled into booklets see G1.7.3.

Fig. G1.7.3 Booklets with students' work (Structural Concepts project)

Feedbacks were collected in order to improve the project, which was done on regular basis, and reasulted in improvement in the quality of submitted works.
Advantages of this particular personalized student centered learning are:
students can learn at their own pace, get more engaged (because they can choose their own topic), the process is done effectively, revision can be done systematically, encourages interest and curiosity, brings attention toward connecting the principles with everyday life - realize how important principles are.
Positive feedback included following appraisal on: visual examples (models and practical examples considered to be very good for improving the understanding), active learning (better then solving numerical tasks), useful for further studies.
The fact, that there was more submissions than the number of students at the end of task points out an interest and an active engagement from the students' side.

Seeing and Touching Structural Concepts

Statics: Bending

Definitions and Concepts | **Model Demonstration** | **Practical Examples** | **References**

Bending

For a beam subjected to bending,

- Elongation occurs on one surface and shortening on the opposite surface of the beam. There is a (neutral) plane through the beam which does not change in length during bending.
- Plane cross sections of the beam remain plane and perpendicular to the neutral axis of the beam.
- Any deformation of a cross section of the beam within its own plane is neglected.
- The normal stress on a cross-section of the beam is distributed linearly with the maximum normal stresses occuring on surfaces farthest from the neutral plane.

Seeing and Touching Structural Concepts

Statics: Bending

Definitions and Concepts | **Model Demonstration** | **Practical Examples** | **References**

References

4.1 Hibbeler, R C, (2005), Mechanics of Materials, Sixth Edition, Prentice-Hall Inc, Sigapore, ISBN 0-13-186-638-9.

4.2 Williams M S and Todd J D, (2000), Structures – theory and analysis, Macmillan Press Ltd, London, ISBN 0-333-67760-9.

4.3 Gere J M, (2004), Mechanics of Materials, Thomson Books/Cole, USA, ISBN 0-534-41793-0.

Fig. G1.7.4a-b **Example from Seeing and Touching Structural Concepts website**
Topic: Bending
Section: Definition and Concepts (a, top), References (b, bottom)[480]

[480] retrieved in July 2019 from: http://epsassets.manchester.ac.uk/structural-concepts/

Seeing and Touching Structural Concepts

Statics: Bending

Definitions and Concepts | Model Demonstration | Practical Examples | References

Model 1 | Model 2

Assumptions in beam bending

This demonstration examines *some of the basic assumptions used in the theory of beam bending.*

(a)

(b)

Fig. 4-4: Examination of beam bending assumptions

A symmetric sponge beam model is made which can be bent and twisted easily (Fig. 4-4a). Horizontal lines on the two vertical sides of the beam are drawn at mid-depth, indicating the neutral plane and vertical lines at equal intervals along the length of the sponge are made indicating the different cross sections of the beam.

Bending the beam as shown in Fig. 4-4b, it can be observed that:

- all of the vertical lines, which indicate what is happening to the cross sections of the beam, remain straight;
- the angles between the vertical lines and the centroidal line (neutral axis) remain at 90 degrees;
- the upper surface of the beam extends and the bottom surface shortens;
- the length of the centroidal (neutral) axis of the beam does not change.

Fig. G1.7.4c **Example from Seeing and Touching Structural Concepts website**
Topic: Bending
Section: Model Demonstration[481]

[481] retrieved in July 2019 from http://epsassets.manchester.ac.uk/structural-concepts/

Seeing and Touching Structural Concepts

Statics: Bending

Definitions and Concepts | Model Demonstrations | **Practical Examples** | References

Example 1 | Example 2 | Example 3 | Example 4

Profiles of girders

(a) (b) (c)

Fig. 4-5: A series of girders supporting windows at airport terminals

Large curtain or window walls are often seen at airport terminals. Fig. 4-5 shows three such walls. These large window walls are supported by a series of plane girders. The wind loads applied on the window walls are transmitted to the girders and through the girders to their supports.

The girders act like vertical simply supported "beams". The bending moments in the "beams" induced by wind loads are maxima at or close to their centres and minima at their ends. If the wind load is uniformly distributed, the diagrams of bending moments along the "beams" will be parabolas. Thus it is reasonable to design the girders to have their largest depths at their centres and their smallest depths at their ends with the profiles of the girders being parabolas. The girders shown in Fig. 4-5c reflect this and appear more elegant than those shown in Figs. 4-5a and 4-5b.

Fig. G1.7.4c **Example from Seeing and Touching Structural Concepts website**
Topic: Bending
Section: Practical Examples[482]

[482] retrieved in July 2019 from: http://epsassets.manchester.ac.uk/structural-concepts/

Understanding and Using Structural Concepts

Rope-inforced Ice!

Rakhshinda Ayub

Concept: Concrete beams are strong in compression but weak in tension. They require reinforcement to provide adequate strength to be used in a structure. Inserting steel at the bottom of the beam where tensile forces are greatest increases its strength as the steel is able to withstand the tensile forces that would usually crack the concrete and cause the beam to fail.

Example: I have demonstrated how this increase in strength using reinforcement can be achieved by comparing two beams made of ice. One will not contain any reinforcement and the second one will be reinforced with string. Their strengths will be compared by loading each of them to test how much load they can carry before failing.

Matrix Material: Ice

Reinforcement Material: Pieces of stapled string

Figure 1: Stapled reinforcement string used in ice beam (2)

Method: Two beams of equal dimensions are made. Beam (1) is not reinforced. Beam (2) has 60 small pieces of stapled string inserted in the water before it freezes to ice. The string is stapled to provide grip in the ice and to prevent all the reinforcement string from floating on the top of the water when forming the ice beam.

Gym weights were used to load the ice beams.

Figure 2 shows beam (1) prepared to be loaded. The stick in the centre of the beam is to ensure that the load applied is a point load at the centre of the ice beam.

Figure 2- unreinforced ice beam(1)

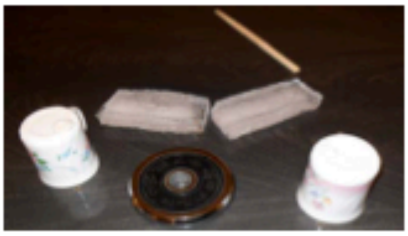

Figure 3 – Ice beam (1) failed under load of 1.25 kg

Fig. G1.7.5a **Seeing and Touching Structural Concepts website**
Example of Student's work p.1/2[483]

[483] retrieved in July 2019 from: http://epsassets.manchester.ac.uk/structural-concepts/

MANCHESTER 1824

The University of Manchester

Understanding and Using Structural Concepts

Figure 4: Ice beam (2) – reinforced beam supporting a load of 11.25kg

The unreinforced beam broke under a load of 1.25Kg. The reinforced ice beam (2) is able to carry a load of 11.25Kg without breaking.

Theory: When the beam is loaded it deforms by sagging as shown in figure 5.

Figure 5: Deflection of a simply supported beam with a central point load

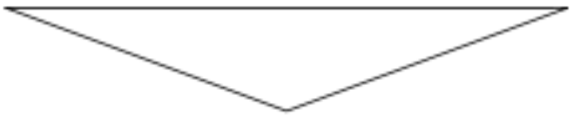

Figure 6: Bending Moment Diagram - simply supported beam with point load in centre

The bottom of the beam is in tension when the beam is loaded. The ice represents the concrete used in beams. This is a brittle material that is weak in tension. The string reinforcement is weak in compression but strong in tension. As the ice is stretched and is about to crack, the string takes the tensile load and prevents the beam from breaking and failing and so increases the strength of the beam.

Fig. G1.7.5b **Seeing and Touching Structural Concepts website**
Example of Student's work p.2/2
Section: Practical Examples[484]

[484] retrieved in July 2019 from: http://epsassets.manchester.ac.uk/structural-concepts/

ABK STUTTGART, GERMANY

The architectural training at the Department of Architecture at Stuttgart State Academy of Art and Design started approx. 250 years ago, when the institution was founded.

The academic year is divided into winter (mid October to February including 2 weeks Christmas break) and summer (April o mid July with 1 week Pentecost break) semesters, lasting between 15-16 weeks each. There are also workshop months from mid September to mid October and for the whole March.

Bachelor programme (B.A.) lasts 6 semesters and one of the conditions for successfully completing the course is **3+2 months internship**.

3 months of manual internship must be completed before starting studies, and students need to produce a report booklet and submit a certificate stating their performance. The internship can be either in the form of a workshop or work at the construction site in the area of wood and/or metal (e.g. at joinery, carpentry, locksmith, art metalwork, industrial repairman site or at training companies in wood, metal, plastic and other structural engineering section. 1 year at vocational school of wood or metal works, where vocational training or draftsmanship took place can also count towards this practice.).
Furthermore, **2 months of the office work** in an architectural or planning office (specializig in architecture, building construction or interior design) are required to fulfill for an admission to the bachelor thesis.
Aprenticeship can be spread into several assignments.
There are the following structural and related subjects in curriculum: **Structural Design I-II** (from modul 03:Structural Design), **Construction Design I-III** (from modul 06:Construction Design), for both of which the course leader is Prof.Dr.Ing.Engelsmann, [485] and

[485] **Prof.Dr.Ing.Stephan Engelsmann**
professor of structural design and structural engineering in the architecture department of ABK since 2002; President of the Baden-Württemberg Chamber of Engineers since 2014; Board member of the Federal Chamber of Engineers; Engelsmann Peters GmbH Consulting Engineers, Stuttgart since 2006; 2005-2009 Head of the interdisciplinary Weißenhof Institute at the State Academy of Fine Arts Stuttgart, 1999-2007 Project manager at Werner Sobek, Stuttgart; 1998-1999 Architectural studies at the University of Bath (UK), 1993-1998 Scientific assistant at the Institute for Construction and Design II, 1991-1993 Project engineer at H.Kupfer, Munich; 1986-1991 Civil engineering studies at the TUM, 1984-1986 Apprenticeship as a bricklayer journeyman, Augsburg, 1st guild winner Elias Holl guild. Source: university's website: visited July 2019.

Fundamentals od Design (modul 09) lead by Prof.Arch.Dipl.Ing.Blaschitz[486]. Catalogue page with the description of Modul 03:Structural Design can be seen in Fig. G1.8.1a-b.

Structural Design Structural Design courses (lectures and exercises) comprise of **Structural Design I** in the first semester 1 and **Structural design II** in the second semester. Both subjects run once a week in 3-hour slot, each is awarded 4 ECTS credits and are taught by J.Strieb. Teaching time of the whole modul is 120 hours, and additional 80 hours are suggested for a selfstudy.

Courses I+II contain an introduction into statics by explaining following topics: **structural loads (deadload, environmental load), equilibrium, internal forces in structure (bending moment, normal force, shear force, bending moment), types of supports, reactions, tension, compression, dimensioning, frames, trusses, stability, shell structures, static analysis, static design**.

Aims of the course: theoretical understanding+practical skills in design, construction and dimensioning load-bearing structures. Intuitivelly capture and analytically assess the force flow of different support systems, develop potential to integrate the supporting structure into the design process in a creative way.

Contents of a course: presentation of common planar and spatial support systems, reduction of complex static systems to simple static models, understanding load-bearing and deformation behaviour, determination of internal forces, approximate design, intuition, cross-material parctical applications.

Exercises: calculations and designs of simple examples

Grading: exam 80%, homework 20%

Construction Design courses in the first year consist of **Construction Design I** in the first semester and **Construction Design II** in the second semester. Both courses run once a week in 3-hour slots, each is awarded 2 ECTS credits. **Construction Design III** in the third semester is in the form of a project, runs three times a week in 4-hour slots and is awarded 12 ECTS. All construction design subjects are taught by prof. Engelsmann and O. Kartkemeyer. Regular individual consultations, colloquia and presentations are also parts of the construction

[486] **Prof.Arch.Dipl.Ing.Mark Blaschitz**
Prof. of Architectural Design since 2010;
2008-2010 Lecturer in design at the Joanneum University of Applied Sciences in Graz (A); 1995-2010 Lecturer at TU Graz (A); 1994-1996 Studied philosophy in Graz (A), Klagenfurt (A) and Vienna (A);1994 Diploma for architecture and urban planning from the TU Graz; co-founder and co-owner of the SPLITTERWERK brand (has been around for over 25 years). Source: university's website: visited July 2019.

group subjects. Net teaching time for the whole modul is 230 hours, additional 170 hours are required for selfstudy.
Aim of the course: proof of a theoretical understanding of building design and structural design, analyze constructional problems and design solutions, overall context, creativity.
Content of a course: material properties, production techniques, design principles, joining technologies, load-bearing behaviour.
Grading: There are following weights assigned to particular parts of the modul: 5% to homework (in sem 1+2), 20% to exams (in sem 1+2) and 75% in to the project in the third semester.

Fundamentals of Design is taught in the 4th semester as a project, which is awarded 12 ECTS as well as a **"Design of your choice" project** in the fifth semester, and **Bachelor project** in the sixth semester.

Master studies last additional 2 years, and students can choose their specialisation.

1	**Modultitel**	Tragwerkslehre (Modul 03)	
2	**Modulkennzeichnung**	Aktualisierungsdatum	15.06.2018
		Modulbereich	B.A. – Studiengang Klasse für Konstruktives Entwerfen und Tragwerkslehre
		Modulform	Semester
		Laufzeit	2 Semester
3	**Modulverwendbarkeit**	Studiengänge	BA Architektur
		Studiensemester	1. + 2.Semester
		Modulart	Pflichtmodul
4	**Modulverantwortliche/r**	Titel, Name	Prof. Dr.-Ing. Stephan Engelsmann
		Fachbereich	Architektur
		Email	stephan.engelsmann@abk-stuttgart.de
5	**Lehr- und Lernformen**	Vorlesung plus Übung plus Hausübung	
6	**Lehrende im Modul**	Dipl.-Ing. Johannes Streib, Prof. Dr.-Ing. Stephan Engelsmann	

Fig. G1.8 .1a Tragwerkslehre Modul description / ABK Stuttgart, p.1/2[487]

[487] retrieved in July 2018 from: https://www.abkstuttgart.de/fileadmin/redaktion/content/hochschule/organisation/hochschulverwaltung/heru

7	**Zum Modul gehörige Lehrveranstaltungen**	Vorlesungen unter anderem zu den Themen Grundlagen und Begriffe, Einwirkungen, Gleichgewicht, Auflagerkräfte, Schnittkräfte, Einfeld- und Mehrfeldträger, Gebäudeaussteifung, Spannungsermittlung, Festigkeitslehre, Bemessung, Stabilität, Fachwerke, Seiltragwerke, Bogentragwerke, Rahmentragwerke; Übungen und Hausübungen zu den Vorlesungen
8	**Voraussetzungen für die Teilnahme**	keine
9	**Lernziele**	Nachweis eines theoretischen Verständnisses von Tragwerken sowie praktischer Fähigkeiten in Entwurf, Konstruktion und Bemessung von tragenden Strukturen. Erwerben der Fähigkeit, den Kraftfluss unterschiedlicher Tragsysteme intuitiv erfassen und analytisch beurteilen zu können. Einordnen der statisch-konstruktiven Aspekte in einen funktionalen, wirtschaftlichen und gestalterischen Kontext. Entwicklung des Potentials, die Tragkonstruktion in kreativer Weise in den Entwurfsprozess integrieren zu können.
10	**Lerninhalte**	Vermittlung der Grundlagen der Tragwerkslehre, bspw. Übersicht über übliche ebene und räumliche Tragsysteme, Reduktion von komplexen Tragsystemen auf einfache statische Modelle, Verstehen des Trag- und Verformungsverhaltens von tragenden Strukturen, Schnittgrößenermittlung und überschlägige Bemessung. Berechnung und Bemessung von einfachen Beispielen in den Übungen. Anschauung und werkstoffübergreifende praktische Anwendung stehen im Vordergrund.
11	**Sprache**	Deutsch

12	**Anzahl der zu erreichenden Leistungspunkte**		8 CP (ECTS)
13	**Arbeitsaufwand für Studierende (1 CP = 25 Arbeitsstunden)**	Präsenzzeit	120
		Selbststudium	80
14	**Form und Gewichtung der Prüfung**	Modulleistung	Klausur plus Hausübungen
		1. Wiederholung	Spätestens zum nächstmöglichen Prüfungstermin
		Anteil an Modulnote	Klausur 80% Hausübungen 20%
		Termin der Modulleistung	Hausübungen über das Semester, Klausur Semesterende
		1. Wiederholungstermin	Spätestens zum nächstmöglichen Prüfungstermin
15	**Voraussetzungen für die Vergabe von Leistungspunkten**	Teilnahme und mindestens bestandene Prüfungsleistungen	
16	**Häufigkeit des Angebots**	Tragwerkslehre I - im Wintersemester, Tragwerkslehre II - im Sommersemester	
17	**Literatur- und Vorbereitungsempfehlungen (Auswahl)**	Literaturangaben zum jeweiligen Vorlesungsthema	

Fig. G1.8 .1b Tragwerkslehre Modul description / ABK Stuttgart, p.2/2[488]

nterladen/studiengaenge/architektur/architektur_ba_ma/abk_stud_arc_modulhandbuch_20180829.pdf

488 retrieved in July 2018 from: https://www.abkstuttgart.de/fileadmin/redaktion/content/hochschule/organisation/hochschulverwaltung/herunterladen/studiengaenge/architektur/architektur_ba_ma/abk_stud_arc_modulhandbuch_20180829.pdf

HCU HAMBURG

The University of Architecture and Spatial Development was founded by the Free and Hanseatic City of Hamburg as a merger of four departments from three Hamburg universities in 2006. It offers courses on architecture, civil engineering, geomatics and urban planning .

The **Bachelor of in Architecture** degree is 6 semesters long, and is awarded 180 ECTS credits.

The first two semesters focus on architectural thinking and composition, on foundation courses and principles, and in faculty's own terms can be characterised as a **VIEW-SHAPE-EXPERIMENT** stage.

The second year attitude can be best described as **RECORD-LINK-APPLY** principles, where coursework specializes in drafting projects related to practice, combines different disciplines, and pays attention to detail.

Finally, the third year curriculum gives the students more flexibility as far as their individual interests are concerned, and is summarised as: **REFLECT-DRAFT** part, where an arbitrary project takes place together with a bachelor thesis.

There is also a compulsory **12 week construction site internship** as a part of the curriculum, a certificate of which students must submit before the end of year 1. In relation to the time schedule possibilities, it is recommended to fulfill this duty before the admission to the bachelor's programme. There is also a possibilty of staying abroad in order to get an international experience, however it is not currently determined by the bachelor's programme, and students need to apply for Erasmus if interested.

The **academic year** consists of winter and summer term, in each of which there are 14 lecturing weeks. The winter term starts in mid October and ends in February (2 weeks of Christmas Holidays included), the summer term starts in April and ends in July. There is one extra week (when there are no lessons) for excursions etc. in the middle of June. Curriculum is dividided into three topical parts: experiments (1st semester), basics (2nd-5th semester), thesis (6th semester). **Studiowork (project)** runs during semesters I-V (awarded 10 ECTS each term), culminating in an **interdisciplinary cooperative project in the fifth term** (with students from programmes like Urban Planning, Civil Engineering, Geomatics, and Metropolitan Culture). The programme is labeled as **A+ programme**.

Introduction into structures starts in the first term by the **Experimental Construction**[489]. The subject is taught by Prof.Dr. Staffa[490], Prof. Dr. Willkomm and Dipl.Ing. Brahms. There are

[489] Experimentelles Konstruieren

[490] **Prof.Dr.Ing.Michael Staffa**

structural engineer and partner in ifb office in Hamburg;

around 100 students in a yeargroup, and the course runs simultaneously once a week for all of them in 3 classrooms. At first, they have a short introduction to a particular topic (cca 15 min), and then continue to work on a task in smaller groups. Several assignments (with progressing difficulty) must be completed during the term, both independent and guided. Compulsory attendance of 80% of the lectures is required, the subject is graded from an essay work (100% weight).

Students create small-scale structural models (e.g. from cardboard), which they submit to a load in order to analyze its behaviour, and in the process they should grasp the structural concepts (get to know basic structural components, learn about structural logic, about supports, load-bearing capabilities etc.). They also improve their structural analysis abilities. The subject is awarded 5 ECTS credits (4 weekly hours per semester), self study for the subject is around 100 hours.

After the introduction, there are three terms of **Structural design**[491] subject awarded 7,5 ECTS each. Prof. Dr. Ing.Staffa is a modul organizer for the first one, Prof. Dr. Kritzmann for vol II and III.

The subject is delivered to students by lectures and seminars, has got 6 to 7 weekly hours per term, and self study is estimated to take around 150 -160 hours per subject per term.

Structural design I represents classification of construction systems with the focus to the dimensional coordination. Term such as **static system, moment line, stress, deformation** etc are explained. **Definition and calculation of a moment** is taught as an introduction to **predimensioning**. Component-oriented cases are discussed during exercises together with practicing constructional drafting. Model building and building analyses are also parts of the course. Participants study the bond between a structure and a design. They need to complete a set of different exercises, attend classes regularly (min 80% attendance), and submit an essay, two-thirds weight of which counts towards the final mark. One third of the final mark is determined by the written examination performance.

Structural Design II is also delivered by a combination of lectures and exercises. Part of the course is focused on **building materials** - mineral building materials, metals, wood and organic materials, synthetic materials, glass (including practical experience in a laboratory), students overall deepen their structural knowledge, and concentrate on a proper joining and layering of the building materials and components (floors, walls, ceilings incl. floor construction, stairs, inclined roofs, flat roofs including openings such as windows, doors and glass constructions). They do pre-dimensioning of support frameworks for **hall structures**

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lecture on relationship between construction and form 16.2.2017 at the Lueneburg Museum. Source: museumlueneburg.de, visited Jan 2019.

[491] also called Construction+Support Structures in some references

whilst using different structural materials. Following topics are looking into: **plate and suspended girders, trussed beams, suspension cables, arches, frames, bracing** etc.

Written examination counts towards one third of the grade, the rest of the grade weight is divided between an essay on building materials (13%) and an essay on structural design (54%). Active participation (min 80%) is requested. Suggested literature for the course is asfollows:

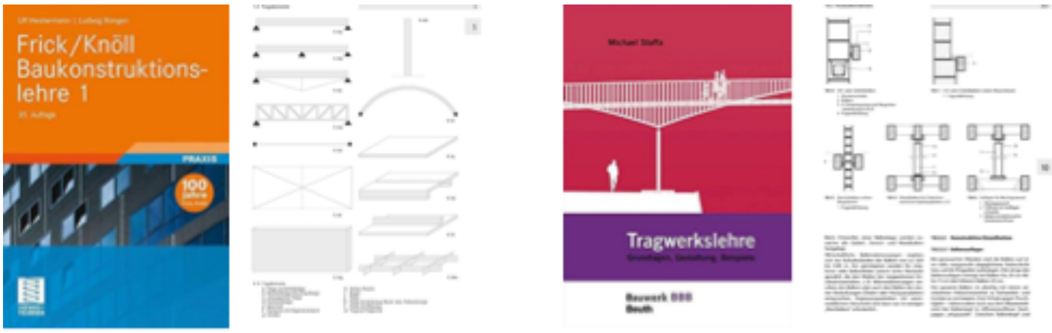

Fig. G1.9.1a-d *__Frick/Knöll Baukonstruktionslehre 1__*, U.Hestermann, L.Rongen, 2015 (36th ed.) (a,b)
Tragwerkslehre: Grundlagen, Gestaltung, *Beispiele*, STAFFA, M., 2014, (c,d)

Fig. 1.9.2a-h EDITION DETAIL KONSTRUKTIONSATLANTEN
Flachdach Atlas, SEDLBAUER, K., 2010 (1st ed.), (a)
Atlas Gebäudeöffnungen, BINDER, M. et al., 2015
Mauerwerk Atlas, G. Pfeifer et al., 2001 (1st ed.), (c)
Holzbau Atlas, T. Herzog et al., 2003 (4th ed.), (d)
Baustoff Atlas, M. Hegger et al., 2005 (1st ed.), (e)
Glasbau Atlas, C. Schittich et al. 2006 (1st ed.), (f)
Fassaden Atlas, T. Herzog et al., 2016 (2nd ed.) (g),
Atlas moderner Stahlbau, A.Reichel et al., 2013 (1st ed.), (h)

Structural Design III builds up on previous knowledge as far as material properties are concerned, which further deepens. Building physics aspects are also taken into account in connection to a structural design. This term is focused to **multi-storey buildings** (their construction systems, support, foundations, solid construction, composite construction...). Pre-dimensioning for multi-storey buildings for its main parts (ceilings, ceiling joists, walls, braces, supports and foundations) is done predominantly empirically (with the help of set formulas, nomographs...). An energy supply concepts (renewable energy etc.) are also looked into during this course. Grading conditions are the same as for previous subjects: 80% min attendance, wrutten exam (1/3 mark weight), two essays (13% weight for Processing Details in Drafts resp. 54% for Support Structure Design). Suggested readings are:

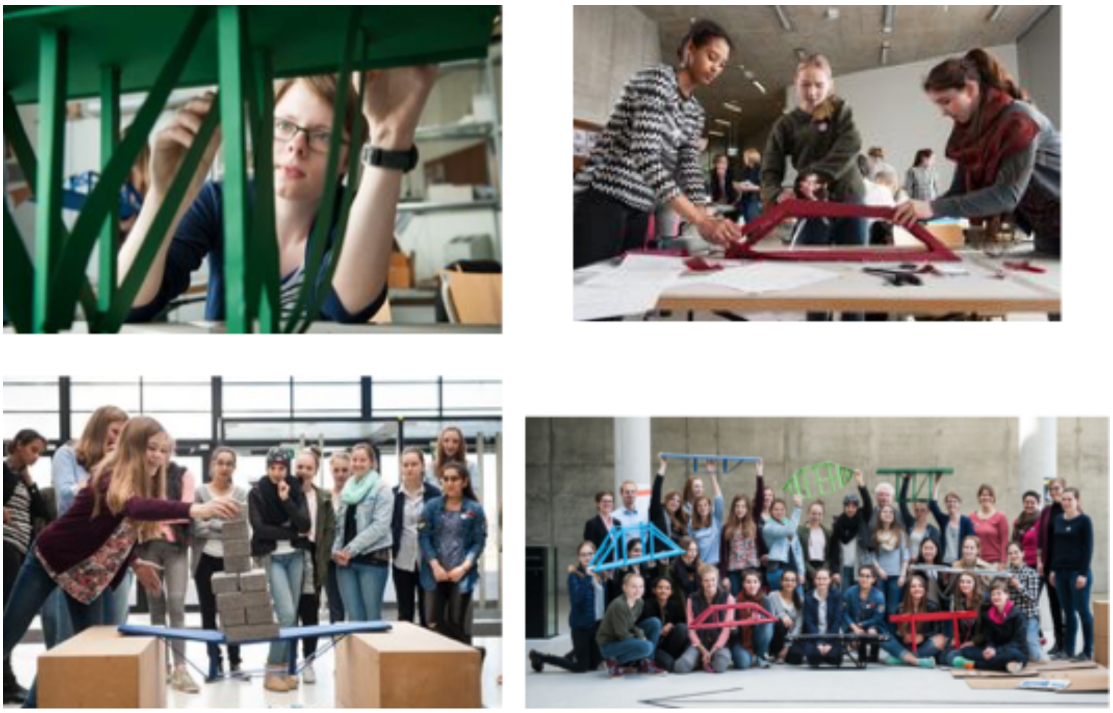

Fig. G1.9.3 Workshop for high-school students

HCU Hamburg is a partner of the NAT[492] Initiative, which promotes interest in natural and engineering sciences in young people in Germany. There is a topical workshop each year in order to bring teenagers's attention towards STEM subjects[493]. **The bridge building workshop** took part in May 2015. Participants from the Heilwig Gymnasium attended a mini-lecture on how the structure and shape work (e.g. they learned, that tubes are more stable than triangles because of its bigger surface area) by graduate engineer Wiebke Brahms, and then

[492] Museum of Science & Technology

[493] **STEM subjects**: science, technology, engineering, mathematic;
in German language: **MINT- Fächer:** mathematik, informatik, naturwissenschaft, technik

build 3-D models out of a cardboard tubes, which they later test-loaded by bricks. The material for each group was limited to two cardboards and a hot glue, and participant were really surprised to see that a structure from a cardboard can hold up to about 22.5 kg load before it breaks. The project is similar to an exercise, which regular architectural students undergo in their first year of studies, however, to make the task more challenging for them, they are not lectured on structural principles beforehand in order to use their critical thinking to a broader extent.

Modulnummer	Modulname	Modultyp (PF/WP/W)	Studiensemester (empfohlen)	Modulverantwortliche
ARC-B-Mod-103	**Experimentelles Konstruieren Tragen - Fügen - Verbinden**	**PF**	**1**	**Prof. Dr. Dahlgrün**

Lehrbereich	Dauer
Architektur	1 Semester

CP (nach ECTS)	Semesterwochenstunden (SWS)	Selbststudium
5 CP (=150 Std. Workload)	4 SWS (= 42 Std. Kontaktzeit)	108 Std.

Ziele und Inhalte

Qualifikationsziel des Moduls (Angestrebte Kompetenzen)
Erlangung der Kompetenz zur Analyse und ersten Anwendung der Grundprinzipien des Tragens, Fügens und Verbindens von Bauteilen zu einem ganzheitlichen Bauwerk durch experimentelles Konstruieren an Modellen. Es wird mit verschiedenen Gestaltungs- und Entwurfsaufgaben der schöpferische Raum des Konstruierens aufgezeigt und die eigene Arbeit zeichnerisch, räumlich und baulich analysiert. Das Qualifikationsziel ist: • Konstruktives Entwerfen als Kernqualifikation realisierender Architekten • experimentell kennenlernen und anwesend erleben und entwickeln zu den wesentlichen Phänomen des Fügens und Verbindens in der Wechselwirkung von Gestaltung, Funktion, Material und Tragwerk • Grundlagenkenntnisse erwerben durch eigene Fragestellungen und alternative Lösungsversuche mit Diskussionen zur Analyse, Bewertung und Anwendung der unterschiedlichen Konstruktionsstrategien
Inhalte des Moduls
• Zunächst elementare und später komplexere kleine Aufgaben mit einfachen Bauelementen sollen hier den Einstieg in die Anwendung konstruktiver Werkzeuge bilden und tragwerkstechnische Bewertungsfähigkeit in der Arbeit ausbilden • Sicherheit im konstruktiven Entwerfen durch konstruktive Prinzipien • Erkennen der Bedeutung konstruktiver Durcharbeitung vom Konzept bis zum Detail als wesentliches gestaltprägendes Element des Architektenentwurfs • Erstes Erkennen der Zusammenhänge von Konstruktionselementen, Tragwerken und Gestaltung • Fähigkeit zur Beurteilung vorhandener und eigener Entwurfs- und Konstruktionslösungen • Erster Einblick in das Wesen / Verhalten von einfachen Tragwerken, ihrer Materialien und konstruktiven Anordnung • Vorlesung + Übung in kleinen Gruppen • Fügen und Verbinden für das konstruktive Entwerfen in Bauwerksanalysen, Modellbau und Zeichnungen • Vermittlung durch Lehrvortrag/Vorlesungen und Arbeit in Seminargruppen • Mehrere Aufgaben pro Semester sind anzufertigen • In praktischen und theoretischen Lernprozessen unter Anleitung und selbstständig die Wechselwirkung von Konstruktion und Entwurf erarbeiten
Empfohlene Literatur
Wechselnd
Lehr- und Lernformen
Experimentelles Konstruieren: 5 CP, Vorlesung und Übung / Seminar (4 SWS) Exkursionen (optional)

Prüfung(en)

Voraussetzung zu(r) Prüfung(en)	
Regelmäßige, aktive Teilnahme (mind. 80%) an Übung/Seminar - Anwesenheitspflicht	
Prüfungsart/-leistung	Prüfungsdauer (bei Klausuren/mündlichen Prüfungen)
Hausarbeit / Semesterarbeit	
Berechnung der Modulnote	
Note der Hausarbeit / Semesterarbeit (100%)	

Fig. G1.9.3 Modul list for Experimental Structures course[494]

[494] retrieved in July 2020 from:

RWTH AACHEN, GERMANY

The faculty of Architecture at RWTH Aachen is located in the Reiff-Museum[495], which opened in 1908[496], although architects were trained at Aachen university since 1878. The building was extended by an annex between 1960-63, and further reconstructions and extension followed soon. Following the Bologna reform, Bachelor and Master programmes were introduced in Aachen in the winter semester of 2006/07. In academic year 2018/2019, there were almost 900 students in bachelor and 700 students in Master architectural courses. 245 students were in the first year group. [497]

At the present time, there is an opportunity for Gymnasium students to enroll in a **"Wegweiser Studium** - orientirung für studieninteresierte" programme at RWTH Aachen, which allows potential study candidates to visit selected lectures (lectures on Structural Design II at the Faculty of Architecture are currently on the list).

The **Bachelor architectural course (BSc.)** at RWTH Aachen lasts 3 years, and the optional **Master sequel (MSc.)** takes another 2 years to complete.

Two main parts of the school year are winter term (from October to January), and summer term (from April to July). There are 14 weeks in each term, but due to various holidays and an excursion week in mid June, a typical course consists of 12 lectures/exercises.

Out of 60 ECTS credits **in the first year of studies**, 5 credits are devoted to Fundamentals of Structures I+II (2 terms), 3 ECTS credits to Materials, 10 ECTS credits to Construction, and 16 ECTS credits to Design.

Structural courses are organised by the Department of Structural Design lead by Univ.Prof.Dr.Ing.Martin Trautz[498], and courses on building construction are coordinated by

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https://www.hcu-hamburg.de/fileadmin/documents/Studium/Modulkarten/2020-21WiSe/Arc-BA-Modulkarten_WiSe2020-21_de.pd

[495] Franz Reiff (1835-1902), Professor of Figure and Landscape Drawing

[496] at that time served both as a museum and a training place for architects

[497] source: university's website, visited July 2019

[498] **Univ.Prof.Dr.Ing.Martin Trautz**

graduated from civil engineering and architecture from the University of Stuttgart (1989); 1989-1990 assisstant to Prof. Schleich at the Institute for Structural Design and Structure; practice: 1990-1991: bridge division of Acer Freeman Fox (UK), 1991-1993 project manager at Ove Arup Leipzig, 1993-1997 researcher (history of structures); 1998 doctorate from University of Stuttgart, topic: On the development of the form and structure of historical vaults from the point of view of statics; 1997/2002 project manager (structural engineering) at the Department of Building Construction lead by Univ.Prof.Dipl.Ing. Hartwig N. Schneider[499].

Fundamentals of Structures I in the first semester focus on the effects on buildings (loads, load setup), and on design of simple, **statically determined** beams (bending beams, supports) in steel and wood. 90-minute lectures (given once a week by Prof. Trautz) are further supported by exercises (taught by 5 assistants once a week, also 90 minutes long).

Fundamentals of Structures II in the second term explain **statically indeterminate** structures, and deal with **designing and dimensioning wood** and **steel** trusses (incl. continuous truss, Gerber truss, Pollonceau truss[500]), **masonry**, **concrete** and **reinforced concrete** structures and dimensioning of their components (beams, slabs, columns). It also describes **graphic statics principles and solutions** (introductory definitions such as vectors, forces, support reactions, and force resultants (Seileck and Poleck method[501]), drawing solution for trusses, Cremona diagram[502]). Topics from static also include: determination of momemt on beams in 2D, dimensioning and construction of trusses (including Ritter's method

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Bolonger+Grohmann, Frankfurt; at RWTH from 2004. Source: http://www.trautz-engineering.com/motivation/, visited July 2019

[499] **Univ.Prof.Dipl.Ing. Hartwig N. Schneider**
studied at University of Stuttgart and at the IIT Chicago; worked wit offices of Prof.von Seidlein (Munich) and Norman Foster (London), found his own architectural office in Stuttgart in 1990; head of Chair of Building Construction at RWTH since 1999. Source: https://hartwigschneider.de/?personen, visited July 2019.

[500] The French railway engineer **Camille Polonceau** (1813-1859) developed in the first half of the 19th century a special type of binder for wide-span railway stations (famous examples: Gare du Nord, Paris, and Westbahnhof, Budapest). According to Polonceau's design principle, the wooden rafters of a gable roof can be considered as under-girders, which are connected to a horizontal drawstring. For the undervoltage and the drawstring, Polonceau had provided wrought iron, so that it was originally a mixed construction, in which the materials were used according to their specific property. Because of the risk of fire, the binders were later made exclusively of iron. Today, Polonceau binders are preferred in sports halls. Here are again mixed structures made of wood and steel for execution. Source: baulexikon.beuth.de, visited July 2019

[501] The **Seileckverfahren** is a drawing method in the statics for determining the resulting force (resultant), from which then, for. B. using the Culmann method, which can determine reactions. If there are several forces in a plane that do not cross at a common point, the position of the resultant can be determined with this method: a figure, the so-called Poleck, is drawn, in which the individual forces are added as force arrows, by size and direction of the resultant, and then connected by pole rays to a point, the pole. The polar jets are then transmitted as so-called ropes in the site plan where they form the Seileck and allow the determination of the line of action of the resultant. The term Seileck is also used in a broader sense for the Poleck. Source: wiki commons.

[502] The **Cremona diagram**, also known as the Cremona-Maxwell method, is a graphical method used in staticsof trusses to determine the forces in members (graphic statics). The method was developed by the Italian mathematician Luigi Cremona. In the Cremona method, first the external forces and reactions are drawn (to scale) forming a vertical line in the lower right side of the picture. This is the sum of all the force vectors and is equal to zero as there is mechanical equilibrium. Source: wiki commons.

of sections for trusses[503]), Mohr's Analogy[504], and calculation of deflections. **Design of a hall with a truss system** (and its dimensioning) is a part of the course's exercises. Lectures and exercises take 90 minutes. See the attached lesson plan of Fundamentals of Structures for the summer term 2018/2019 in the Fig G1.10.5.

Construction in year 1 starts with a theory on principles, methods and various structural techniques. In the practical part of the subject, there are supervised exercises, where simple structures are constructed and the design of different structures is practiced. Project work is also practice-based as designing and constructing is understood as a simultaneous process. There are also the basics of joining components with different design principles tested as a preparation for the second semester basics of building construction as well as modelmaking and presentation.

In the **second year** of architectural studies at RWTH at Aachen, similarly 5 ECTS credits are devoted to follow-up courses on structure: Structural Design I+II (taught by a team of different lecturers according to the topic specialisation), and 8 ECTS to Construction. Design projects are awarded 12 ECTS credits in the third term, resp. 15 ECTS credits in the **fourth term** for an **interdisciplinary project specialised on the structure**. Here, structural concepts should be presented by alternatives, supporting structures must be optimally designed, taking into account comprehensive structural engineering aspects.

Structural Design I (90-minute lectures) in the third semester focuses on rough dimensioning and load-bearing structures of: **foundations, roof structures, cable structures, arch structures, and frame structures.** It also continues to deal with the design of hall structures.

[503] The **Rittersche Schnittverfahren** goes back to August Ritter. It is used for structural analysis for the calculation of internal forces in general of trusses. For a system to be in equilibrium under the action of given forces, it is necessary and sufficient for each subsystem to be in a balance of all the forces acting on it. It is generally useful for statically determined structures to calculate all bearing forces before applying the knight cut. Before determining the bar forces, it makes sense to first determine any zero bars according to the applicable rules. Source: wiki commons.

[504] **Mohrs Analogy** exists between the actual deformation quantities (curvature, cross section angle of rotation, deflection) and the ideal force variables (linear load, lateral force, bending moment) on the replacement carrier. Mohr's analogy allows the calculation of imaginary internal forces (with the help of equilibrium conditions) instead of solving the present kinematic task also results from the analogies, the ideal line loads (= curvatures) can be replaced for each bar by two statically equivalent W-weights (angular weights) at the bar ends. Source: baulexikon.beuth.de, visited July 2019.

Structural Design II (90-minute lectures) covers the following topics: practical reinforced concrete construction, **rope-tensioned** load-bearing structures, cable-stayed constructions, **lightweight metal** structures, **pneumatic** structures, **movable** constructions (e.g. opening bridges), **spatial** structures, **facade** systems, girder grids, **glass as a construction material**, approximation methods for the **approximate dimensioning** of structures and constructive structural details. The detailed lesson plan for the Structural Design II can be seen in Fig. G1.10.6. At the end of the term, there is a **3-day compulsory colloquium** as a part of the subject.

Construction in year 2 specializes in skeleton structure. There are several smaller exercises for designing and constructing structures in the winter term, and the already mentioned cooperative structural project, which takes place in the summer term. Apart from the skeleton systems, there are also lectures on wooden structures, steel structures and facade systems incorporated.

Fig. G1.10.1 Prof. Gerhardt and his colleague demonstrating structural behaviour

Dr.Ing. Rolf Gerhardt received Teaching Award SS 2012 (by the Fachschaft Architektur) for the concept of **Structural Mechanics I** (Basic Principles) and **Structural Mechanics II** (Structural Design) lectures and exercises in the first two terms of studies, which has been assessed as "particularly vivid" and "generally understandable". Dr. Gerhardt also introduced students to graphic statics.

Fig. G1.10.2 Prof. Gerhardt's textbook on graphic static approach

In his book ***Illustrative structural theory - experimental representation of bending moments with the help of the rope line (reports from the construction industry)***[505], he addresses the problem of an increasing loss of clarity of structural engineering due to its development and constant refinement originating back in the 18th century (beginning of scientific structural engineering)[506]. Gerhardt thinks that there should be a certain balance to the calculation methods (whose mathematical-abstract character no longer allows correlations to be easily recognised) customary used in engineering practice. According to his opinion, the universities' call for scientifically based presentation of the teaching content does not have to be in conflict with the desire for clear and memorable structural theory, as this can be achieved by the means of graphic statics.

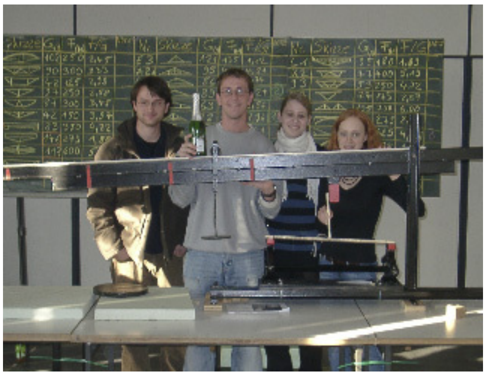


Fig. G1.10.3 "The Breaking Trial" initiated by the Department of Structural Design in 2008

Fig. G1.10.4 Bamboo workshop organised by RWTH in 2004 in Luxemburg, "Bamboo Dome 4U"

RWTH further motivates students by various activities. One of them is "The Breaking Trial"[507] initiated by the Department of Structural Design for the first year's students, who are (in a group of four) challenged to build models, which are later submitted to the increasing loading until the structural failure. Bamboo structural workshop[508] represents the other example.

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[505] original German title: Anschauliche Tragwerkslehre-Experimentelle Darstellung von Biegemomenten mit Hilfe der Seillinie (Berichte aus dem Bauwesen): GERHARDT (2002)

[506] described impressively in detail by Hans Straub in his work: ***The History of Civil Engineering***

[507] http://arch.rwth-aachen.de/cms/Architektur/Die-Fakultaet/Aktuell/Nachrichten/~clvd/MyReiff-HTML-Einzelansicht/?file=2008-01-09, visited July 2019

[508] https://docplayer.org/13421929-Lehrstuhl-fuer-tragkonstruktionen-rwth-aachen-bambus-am-lehrstuhl-fuer-tragkonstruktionen.html, visited July 2019

https://bambus.rwth-aachen.de/de/fr_bambuskuppel_4u_eng.html , visited July 2019

ARCHITEKTUR

TRAGKONSTRUKTIONEN
Univ.-Prof. Dr.-Ing. Martin Trautz

Grundlagen der Tragwerklehre II SS 2019

Termin	Datum	**Vorlesungen** (ab 14.05.2019:) Prof.-Pirlet-Straße PPS H2 (2315|001) **Di., 10:15 – 11:45 h**		**Übungen** Reiffanbau u. Baumhaus **Di., 12:00 – 13.30 h**
01	02.04.19	Graphische Statik - Herkunft, Vektoren, Kräfte und Auflagerreaktionen	Tr	Ü1: Graphostatik 1
02	09.04.19	Graphische Statik - Seileck und Poleck	Tr	Abgabe Ü1 Ü2: Graphostatik 2
03	16.04.19	Momentenermittlung von lastaffinen Geometrien und Träger im Zweidimensionalen	Tr	Abgabe Ü2 Ü3: Momentenermittlung und Träger im Zweidimensionalen
04	23.04.19	*** keine Lehrveranstaltung ***		Übung ohne Ausgabe
04	30.04.19	Fachwerke, zeichnerische Lösungsverfahren = Cremonaplan	DG	Abgabe Ü3 Ü4: Fachwerkträger
	07.05.19	**** Fachschaftsvollversammlung ****		keine Lehrveranstaltung
05	14.05.19	Fachwerksysteme und Polonceau-Träger Cremo-napläne	DG	Abgabe Ü4 Ü5: Cremonaplan
06	21.05.19	Fachwerkträger: Schnittverfahren nach A. Ritter 'Hebelarm-Methode'	DG	Abgabe Ü5 Ü6: Entwurf Fachwerkhalle
07	28.05.19	Bemessung von Fachwerkträgern	AP	Abgabe Ü6 Ü7: Schnittkraftermittlung und Bemessung
08	04.06.19	Konstruktion von Fachwerkträgern	AP	Abgabe Ü7 Ü8: Konstruktive Ausbildung
	11.06.19	*** Exkursionswoche ***		keine Lehrveranstaltung
09	18.06.19	Mohr'sche Analogie, Durchbiegungsberechnung	Tr	Abgabe Ü8 Ü9: Durchbiegungsberechnung
10	25.06.19	Durchlaufträger und Gerberträger, semi-graphisches Verfahren	Tr	Abgabe Ü9 Ü10: Durchlaufträger
11	02.07.19	Beton- und Stahlbetontragwerke, Bemessung von Stahlbetonbalken	JM	Abgabe Ü10 Ü11 Stahlbetonbalken
12	09.07.19	Stahlbetonplatten und -plattenbalken, einachsig gespannte Stahlbetondeckensysteme	JM	Abgabe Ü11 Ü12 Stahlbetonplattenbalken

Stand: 14.05.2019
AP

Fig. G1.10.5 Fundamentals of Structures II lessons plan (school year 2018/2019) [509]
2nd Term, Summer Term in Year 1

[509] retrieved in July 2019 from: http://trako.arch.rwth-aachen.de/cms/TRAKO/Studium/~luem/Sommersemester-2018-19/

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TRAGKONSTRUKTIONEN
Univ.-Prof. Dr.-Ing. Martin Trautz

Tragwerklehre II / Projekt B2 SS 2019
(4. Fachsemester)

Termin	Datum	**Vorlesungen** MAGMA-Hörsaal (H 218) (1390|218) **Do., 10:15 – 11:45 h**		**Projektbetreuung** Arbeitsräume / Reiff-Foyer **Mi., 08:15 – 15:30 h**
01	04.04.19	Einführung in den Tragwerkentwurf und die relevante Tragwerktypologie	Tr	03.04.19 1. Teambetreuung
02	11.04.19	TW-Typen I Trägerroste, Raumfachwerke	Tr	10.04.19 2. Teambetreuung
03	18.04.19	TW-Typen II Seilverspannte Tragkonstruktionen	Tr	17.04.19 **1. Rundgang**
04	25.04.19	Innovative TW I Metallleichtbau	Tr	24.04.19 Individualbetreuung 1
	01.05.19	*** Tag der Arbeit ***		
05	02.05.19	Fassadenkonstruktionen	TP	
06	09.05.19	Diskussion ausgewählter Tragkonstruktionen	Tr	08.05.19 3. Teambetreuung
07	16.05.19	Innovative TW II Bewegliche Tragkonstruktionen	Tr	15.05.19 **2. Rundgang**
08	23.05.19	Konstruktive Tragwerkdetails	He	22.05.19 Individualbetreuung 2
				29.05.19 Individualbetreuung 3
	30.05.19	*** Christi Himmelfahrt ***		
09	06.06.19	*Praktischer Stahlbetonbau*	Tr	05.06.19 Individualbetreuung 4
	13.06.19	*** Exkursionswoche ***		*** Exkursionswoche ***
				19.06.19 **3. Rundgang**
	20.06.19	*** Fronleichnam ***		
10	27.06.19	*Konstruktive Tragwerkdetails im Massivbau*	*JM*	26.06.19 4. Teambetreuung
11	04.07.19	Keine Vorlesung		03.07.19 Individualbetreuung 5
12	11.07.19	Keine Vorlesung		10.07.19 Keine Betreuung (Ausarbeitung)
13	17. bis 19.07.19	**ABGABEKOLLOQUIEN** Mi., 17.7., Do., 18.7., Fr., 19.7. (Umtrunk am Abend)		

Stand 29.03.2019
He

Fig. G1.10.6 Structures II lessons plan (summer term 2018/2019) [510]
4th Term, Summer Term in Year 2

[510] retrieved in July 2019 from:
http://trako.arch.rwth-aachen.de/cms/TRAKO/Studium/Sommerrsemester-2018-19/~luer/Copy-of-Grundlagen-der-Tragwerklehre/

TECHNICAL UNIVERSITY OF MUNICH, GERMANY

In 1868, King Ludwig II founded the newly structured Polytechnische Schule München, which had the status of a university, in Munich. The college was divided into five sections, one of which was the Department of Architecture[511].

Nowadays it has got 1,500 students in Bachelor, Master and Postgraduate studies.

According to **THE** (Times Higher Education) **World University Ranking (2019),** architectural studies at TUM belong to top 31 universities worldwide, hold the 6th position within Europe (4th within European Union) and by far **number 1 in Germany**.
Similarly, at **QS World University Ranking 2019** (Subject Architecture), the Department ranks among top 25 worldwide, top 10 within Europe, and in general as No.1 university throughout Germany.
TUM is also one of the five universities with the highest DFG funding in the field of construction and architecture and The University Ranking by Academic Performance, (URAP) lists TUM among the top 75 in the discipline of architecture worldwide.
Ten of its professors are permanently listed in the Baunetz ranking.

The **Bachelor of Arts in Architecture** degree programme is **8 - semester** long. The first four semesters consist predominantly of mandatory courses. Its core subjects are awarded 30 credits per semester, which correspondes to 20 weekly hours per semester. In the **5th and 6th semester**, most students study at a **foreign partner** university. In these two semesters they need to fulfill only 20 credits per semester. In the **7th semester**, students can **choose a project** from variety of topics offered by different chairs of the Department. The rest of their curricula are **compulsory elective modules**, which give the students an opportunity to specialize. The 8th semester is reserved for students' **Bachelor thesis project** they present at a final colloquium.
The **Master of Arts in Architecture** degree programme is **4 - semester** long. The main part of the programme is represented by an individual project, and students further complement their curricula from the broad offer of elective courses. Certified specialisations are also offered as well as mentoring programmes. The last semester is reserved for completing the **Master thesis**.

[511] source: wiki commons

The study plan for the first term of Year 1 contains following subjects related to the structure: **Project 1** (Projektarbeit 1), **Construction 1** (Baukonstruktion 1), and **Statics** (Statik und Festigkeitslehre). Construction and Statics are equally awarded 6 ECTS credits each (4 x 45 min slots p.w.), the Project holds 8 ECTS credits (6 x 45 min slots p.w.) out of total of 30 ECTS credits per semester. As far as the school year organisation is concerned, there is Winter semester running from October to February, and Summer semester running from April to July at TUM. One semester consists of 14 weeks.

The **Project 1** is provided by **The Chair of Architectural Design and Construction** (Lehrstuhl für Entwerfen und Konstruieren) led by Prof. **Nagler**[512]. As a part of their coursework, students need to create 5-10 plans and 3-5 models, which they present within 10 minute slot at the end of semester. They need to take into account not only architectural questions on space, but also material and construction possibilities.

Accompanying lectures **Construction 1** (taught by Prof. Nagler) provide theoretical basis for the project. After completing the course, students should be able to understand and apply the main principles of building construction, distinguish the function of different parts of the structure (foundations, wall, openings, ceilings, roof, stairs...) and use them accordingly, be aware of the interdependence between space formation and constructional possibilities, use various materials accordingly with their specific properties, and understand overall construction process. Four units of teaching time are distributed as follows: lecture on design methodology and building theory: 2 units per week, lecture on the basics of building construction: 1 unit p.w., preparing building analyzes in group work and present them during the lecture: 1 unit p.w..

Statics lessons in the first semester are provided by **The Chair of Structural Design** (Lehrstuhl für Tragwerksplanung), led by Prof. **Rainer Barthel**[513] who also teaches the

[512] **Prof. Florian Nagler**
originaly trained as a carpenter, and then studied architecture at the University of Kaiserslautern.
visiting and acting professorships at: University of Wuppertal, the Royal Danish Academy of Fine Arts in Copenhagen and the Hochschule für Technik in Stuttgart; founding member of the Bundesstiftung Baukultur foundation; member of the Academy of the Arts, Berlin – Architecture section, and the Bavarian Academy of Fine Arts since 2010; research interests: exploring the relationship between design and construction. Source: university's website, visited Jan 2019.

[513] **Prof. Rainer Barthel**
civil engineer; research areas: design and development of load-bearing structures and the analysis and restoration of historical load-bearing structures, the relationship between the form of bearing structure, design and architectonic form (particular interest); graduated from the University of Stuttgart, and completed his doctoral thesis "Bearing behavior of masonry cross-vaults" at the University of Karlsruhe; prior to his

subject. It consists of a lecture (Vorlesung), which takes part once a week for 90 min in the morning, and is followed by an exercise (Übung) lasting 90 min in the afternoon. There are basics of statics and strength theory explained at the lectures, and then applied in exercises, which together with excursions to see the real building structures help to grasp the concept. Part of the exercises is also devoted to testing structural models in order to validate some of the theories. Students regularly get homework to test their knowledge. Digital abstracts of lectures are available as well as script, handouts, and online platform to support the course. **After completing the course**, students should have basic knowledge about theory of static calculations, should be able to explain simple structures through mechanical models and should be able to analyse them with the basic mechanical laws. **Topics covered** are as follows: **mechanical terms of force and moment, equilibrium conditions, static systems, basic multipart load-bearing structures, plane trusses, internal forces in beam structures, catenary and line of thrust, resistance moment and moment of inertia, axial and bending stresses, deformations** and **stability**. The lesson plan for Statics can be seen in Fig. G1.11.7 and the course textbooks in Fig. G1.11.1 a-e.

Fig G1.11.1a-e STUDY LITERATURE for STATICS LESSONS in YEAR 1
Grundlagen der Tragwerklehre 1, KRAUSS, F. et al., 2014, (a)
Grundlagen der Tragwerklehre 2, KRAUSS, F. et al., 2011, (b)
Tabellen zur Tragwerklehre, KRAUSS, F. et al., 2014, (c)
Formeln und Aufgaben zur Technischen Mechanik 1: Statik, GROSS, 2016 (12 th ed.), (d)
Technische Mechanik 1: Statik, GROSS, D., 2019 (14 th ed.), (e)

Set up of the courses in the second semester of year 1 stays more less the same. There is **Project 2**, **Construction 2** and **Load-bearing Structures** (as follow-up of Statics) with the same number of teaching units devoted to them as in the first term. In total these subjects take 20 ECTS credits out of 30 ECTS credits per term.

appointment to the Chair of Structural Design at TUM in 1993, he was a project manager at eng. comp. Wenzel (Karlsruhe) and at Ove Arup & Partners (London); with a partner founded engineering company Barthel & Maus Beratende Ingenieure GmbH (1996); 1999-2000 Dean of the Faculty of Architecture; 2009-2012 visiting lecturer at ETH Zurich. Source: university's website, visited Jan 2019.

Project 2 and Construction 2 subjects are provided by **Associate Professorship of Architectural Design and Timber Construction department** (Professur für Entwerfen und Holzbau), which is led by Prof. **Kaufmann**[514].

Construction 2 takes time twice a week in the form of a lecture lasting 90 minutes each. One lecture per week is devoted to principles of building design theory (building typologies, functional principles of building, human proportions, dimensional system), and the other one to applying these principles to the wooden structures. Students get acquainted not only with building elements of wood (walls, openings, ceilings, roofs, stairs, windows, interior finishes), but also with principles of wooden structures, material properties of wood, wood preservation, fire protection, thermal insulation and building regulations and standards.

Fig G.1.11.2 a-d RECOMMENDED LITERATURE for CONSTRUCTION COURSES in YEAR 1
Holzbau Atlas, HERZOG, T. et al., 2003 (4th ed.), (a)
Holzbau Atlas Zwei, HERZOG, T. et al., 2001 (1st ed.), (b)
Holzbau mit System, KOLB, J., 2008 (2nd ed.), (c)
Architektur konstruieren: Vom Rohmaterial zum Bauwerk, DEPLAZES, 2018 (5th ed.), (d)

Project 2 is connected with Construction 2 lectures, therefore students design a small wooden building, for which they choose appropriate construction system and work out the main construction details. The first half of the semester is a preparatory phase, when students study aspects of designing timber structures on selected examples. For their main project, they need to produce a manually drawn draft, construction and detail technical plans and several self-

[514] **Prof. Hermann Kaufmann**
studied architecture at TU Innsbruck and TU Vienna; 1995-1996 lectured in timber construction at the Liechtensteinische Ingenieurschule – the Engineering College of Liechtenstein; visiting professor at TU Graz (1998) and the University of Ljubljana (2000);
Director of the Chair of Timber Construction at the Institute for Architectural Design and Building Technology of TUM; member of several associations e.g. the Austrian Federal Chamber of Engineers and the Central Association of Austrian Architects. Source: university's website, visited Jan 2019.

made models (2-3 on different scales). They need to explain their design idea, demonstrate a functional spatial relationship of a structure and provide a structural analysis as well.

Load-bearing Structures course consists of 90 min lectures in the morning, and 90 min exercises in the afternoon of the same day. It is provided by the Chair of Structural Design and taught by prof. Barthel. At the end of the course, students should be able to **identify and analyse load-bearing structures and also develop them** as a part of their architectural design. They should have an **idea about dimension ranges** and should be **able to predimension and design the essential elements of common structures**. The course focuses on load-bearing elements and structural systems for building constructions as well as on their bracing. The students are given insight into the function, design, engineering and dimensioning of load-bearing structures. They get acquainted with the most important structural design methods for **reinforced concrete, steel and wooden structures** and they study structural behaviour of individual construction elements such as **columns, beams, frames, trusses, cables, arches, etc**. They learn an approximate dimensioning of these elements. Students get regular homework to practice their knowledge and skills.
There is a script accompanying lectures, students also get handouts. Recommended further reading as seen in Fig. G1.11.3a-c. The lesson plan for the Load-bearing Structures can be viewed in Fig. G1.11.8.

Fig G1.11.3 a-d LITERATURE for LOAD-BEARING STRUCTURES COURSE in YEAR 1
(recommended)
Holzbau Atlas, HERZOG, T. et al. T., 2003 (4th ed.), (a)
Stahlbau Atlas, HABERMANN, K.J. et al., 2001 (1st ed.), (b)
Beton Atlas, KIND-BARKAUSKAS, F. et al., 2001 (2nd ed.), (c,d)

Project 3 and 4 in the second year of the architectural studies at TUM keep an important position in curricula with 8 ECTS credits each term, but there is only **Construction 3** in the winter term (6 ECTS) of a study plan.

Both **Project 3** and **Construction 3** focuses on material, and is guaranteed by the **Chair of Building Construction and Material Science** (Lehrstuhl für Baukonstruktion und Baustoffkunde), head of which is Prof. **Florian Musso**[515].

In **Project 3**, students work both individually and in groups on a building task of average complexity (concrete construction). Besides other they must be able to demonstrate their knowledge of construction, material and technical requirements such us statics, building technology and building physics. As an output, they need to present 8-12 plans and project further accompany by other means of their choice (e.g. perspectives, sketches, models...). Presentation takes 20 min. Individual performance is monitored throughout the term by marking separate parts of project. On demand, the consultants can communicate in English language. The main focus of the course is material solution and attention to structural detail. For some parts of the structure (floor, ceiling, wall, roof and facade as well as the associated connection points), students are required to produce 1:1 details. Students will learn how to work out foundations for an architectural design by analyzing what already exists. The subject is supoorted by lecture Construction 3 on a theoretical level.

After completing **Construction 3**, students should be able to recognize the properties of the main building materials, to combine them and to judge their proper use within the structure. They should be also able to design proper structural details. The course examines the relationships between building materials, building construction and an architectural form. Also explains the design of buildings' foundations.

Project 4 in the second semester of year 2 is focused on urban design, year 3 spend students individually abroad. The 7th semester is reserved for going through management and legislation, and in the 8th semester students work on their Bachelor Thesis.

[515] **Prof. Dipl.Ing. Florian Musso**
studied architecture at Stuttgart University and UVA in Charlottesville, USA; worked as an architect and assistant at ETH Zurich, ETH Lausanne and RWTH Aachen. Before taking up his post at TUM in 2002, he was a lecturer at EIA Fribourg, Switzerland, and a guest professor at the University of Pennsylvania in Philadelphia, USA. He was also a guest professor at the University of Arizona in Tucson, USA in 2005;
has been running an architect's office in Sion, Switzerland since 1988 and in Munich since 2002 (together with Claudine Lorenz); research interests: construction materials and subsystems in industrial construction. Source: university's website, visited Jan 2019.

Workshops are regular part of the structural curricula at TUM as seen below:

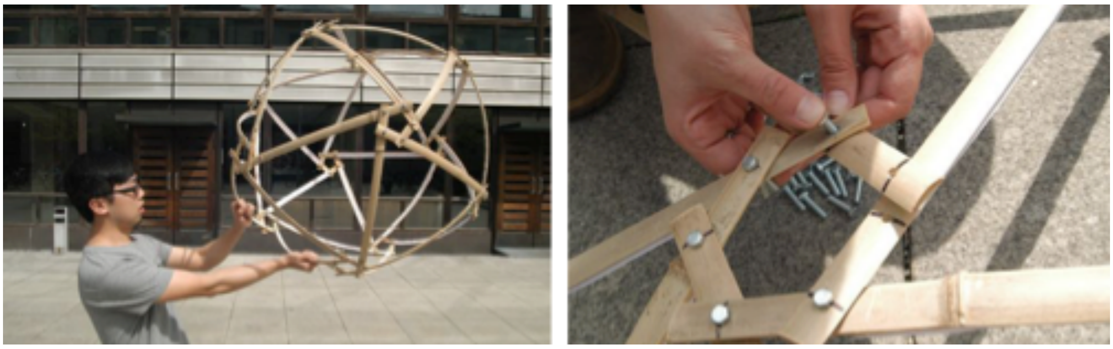

Fig. G1.11.4 Workshop 2016 : CURVATURE - BENDING THE RULES

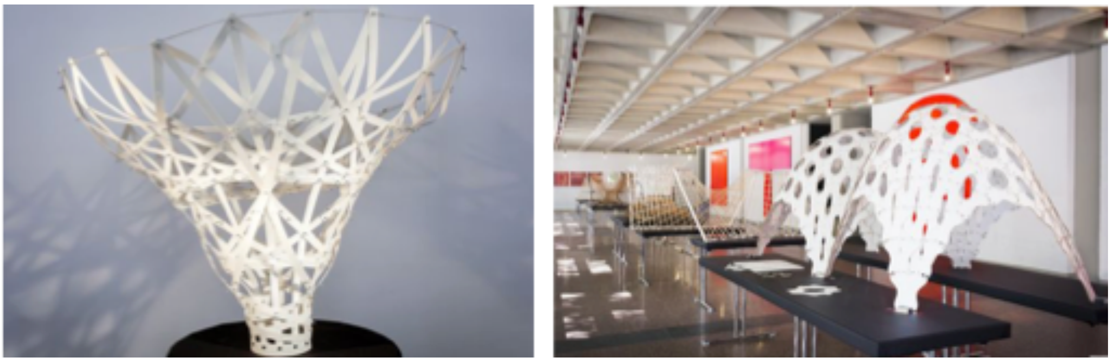

Fig G1.11.5 Workshop 2017 : GRIDSHELLS

Summer school workshops are also regularly organised.[516]

Fig. G1.11.6 Summer school 2018 (left)
Summer school 2019 (right)

[516] https://www.ar.tum.de/en/international-affairs/singleviewinter-en/article/summer-school-architecture-and-champagne-2019/, visited July 2019

I.1.1.1 *Termine im WS 2018/19:*

Vorlesung (Dozent Prof. Dr.-Ing. Rainer Barthel): Montags, 14.00-15.30 Uhr, HS 0602
Übung: Montags, 15.45-17.15 Uhr, HS 0602

Erster Vorlesungstermin im WS 2018/19: Montag, 22.10.2018, 14.00 Uhr, HS 0602

Datum	Vorlesung	Übung
22.10.2018	Einführungen in die Themen der Tragwerkslehre	
29.10.2018	Modellversuche	
05.11.2018	Grundlagen: Kräfte und Momente	Ü1 Hebelgesetze, Schwerpunktbestimmung
12.11.2018	Gleichgewicht	Ü2 Auflager, Auflagerreaktionen
19.11.2018	Mehrteilige Tragwerke	Ü3 Gelenkträger, Dreigelenkbogen
26.11.2018	Fachwerke	Ü4 Stabwerke in Fachwerken
03.12.2018	Lastabtragung	Ü5 Lastabtragung
10.12.2018	Schnittgrößen	Ü6 Schnittgrößen am Biegeträger
17.12.2018	Exkursion	
07.01.2019	Normalkraftwirkung	Ü7 Elastizitätsmodul, Dehnung
14.01.2019	Biegewirkung	Ü8 Trägheitsmoment, Widerstandsmoment
21.01.2019	Querschnittsbemessung	Ü9 Vordimensionierung
04.02.2019	Prüfungsvorbereitung	Prüfungsvorbereitung
15.02.2019	Prüfung	

Fig. G1.11.7 Statics lesson plan (school year 2018/2019)[517]
1st Term, Winter Term in Year 1

[517] retrieved in Jan 2019 from https://www.ar.tum.de/lt/lehre-studium/architektur-ba/statik-und-festigkeitslehre/

I.1.1.2 Termine im SS 2018

Montag, 09.45-11.15 Uhr (Vorlesung) und 11.30-13.00 Uhr (Übung)
Hörsaal 0606

Termin	**Vorlesung**	**Übung**
09.04.2018	Skriptverkauf, Einwirkungen	Einwirkungen auf Tragwerke
16.04.2018	Biegetragwerke	Zeichenübung
23.04.2018	Fachwerke	Lastabtragung
30.04.2018	Besprechung Übungsentwurf	
07.05.2018	Unterspannungen	Unterspannte Träger, Analyse Brücke
14.05.2018	Rahmen	Rahmen
21.05.2018	*entfällt (Pfingstmontag)*	
28.05.2018	Verbindungen im Stahlbau	Besprechung Übungsentwurf (AP2
04.06.2018	*entfällt (Exkursionswoche)*	
11.06.2018	Exkursion Flugwerft	Übung am Bauwerk
18.06.2018	Bogentragwerke	Besprechung Übungsentwurf
25.06.2018	Seiltragwerke	Sammelsprechstunde Übungsentwurf
02.07.2018	Stahlbetontragwerke	Präsentation / Feedback Übungsentwurf
09.07.2018	Prüfungsvorbereitung	

Fig. G1.11.8 Load-bearing Structures lesson plan (school year 2018/2019)[518]
2nd Term, Summer Term in Year 1

[518] retrieved in Jan 2019 from
https://www.ar.tum.de/lt/lehre-studium/architektur-ba/tragkonstruktionen/

UDK BERLIN, GERMANY

The Universität der Künste Berlin (UdK; Berlin University of the Art) is public art and design school with full university status, comprisis of four colleges, one of which is the **College of Architecture, Media and Design.**

The Architectural study programme at UdK is currently oganised by two institutes: the Institute of Architecture and Urban Planning (IAS) and the Institute for the History and Theory of Design (IGTG). Both institutes belong to the College of Architecture, Media and Design. The first Dean and co-founder of the Architectural study programme was an architect Max Taut, who from 1945 to 1953 worked here as a professor and director of the Department of Building and Architecture. Since 1995, there is a Max Taut prize awarded to the outstanding students.

As stated on college's website, the aim of architectural studies at UdK Berlin is "to develop each student's autonomous artistic-design standpoint on a **solid constructive-technological foundation**".

Every year, there are 50 students accepted to the Bachelor Degree programme (4 years duration, 240 ECTS credits in total) and 40 to the Master Degree course. An interaction between study programmes is encouraged by a **transdisciplinary project UdK Campus-Collisions** (started in winter term 2013/14), which supports and promotes an artisctic-scientific atitude to learning. Practical experience and time spent abroad are compulsory for each student, some departments also offer billingual teaching in English. There is a winter term from mid October to February and a summer term from April to July.

Overall study plan is divided into 16 modules (4 each year). Each modul contains 2-5 topically similar subjects. Group "Construction and Technology 1" is **modul 3 in year 1,** which contains besides others subjects **Structural Design I** and **Building Structures I** in the first and second term (awarded 5 ECTS each, taught 90-min weekly in the combined form of lectures and exercises each). Group "Construction and Technology 2" is **modul 7 in year 2**, and is organised analogically to modul 3 in year 1. Group "Construction and Technology 3" is **modul 11 in year 4**, which has got the same subject structure and hourly dotation, but they are taught in winter term only. The person, who is responsible for structural subjects at UdK is **Prof. Gengnagel**[519], (who developed the current form of most of them with then

[519] **Prof.Dr.Ing. Christoph Gengnagel**

university's research assistant Gregory Charles Quinn). He also teaches most of them in cooperation with his colleagues (Dipl.Ing.Prokop (Struct.Des.I), Dipl.Ing.Alpermann (Str.Des.II), and Prof.Dr.Palz (Building.Str.I+II)).

The aim of structural subjects is for students to become able to intuitively grasp and analytically assess the force flow in different types of structures. Students learn how to determine support reactions and internal forces of truss, rope, arch and frame structures. They also study in detail material properties and their influence on the structural design. As a study material for the courses, *TUM Tragwerklehre* scriptum is used.

Augmented and virtual reality structures

As described in the conference paper,[520] a prototypical augmented reality tool **StructAR** has been developed by **Gregory Quinn**[521]. The gadget has been created as a teaching tool aspiring to enhance an intuitive grasping of SE concepts. In the principle, it allowed to watch changing internal forces on a structural model (bending moments, axial forces and shear forces) in accordance with changing external loads of the model (physical interaction with the object). It was provided by the means of augmented reality (projection of the images created by synchronous simulation of the same system).

The model of the structure was made out of 3 mm GFRP[522] rods by joining them together (e.g. in the shape of a portal frame) and pinning them onto a projection board (1m x1.4m big) made out of a plywood containing an array of 20 cms distant holes, to which "joining parts" (a custom pin, a roller and a rigid supports) could be inserted. See Fig. G1.12.1.

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focuses on digital and phzsical prototzping in architecture and engineering, computational design and new material szstems; studied construction engineering and architecture at Bauhas University at Weimar and Technical University Munich (PhD from TUM); formerly structural engineer at Dywidag Munich, Barthel&Maus and a.ka. Ingenieure; consulting partner of Bollinger+ Grohman; previous academic posotions at TUM and the Rozal Academz of the Arts at Copenhagen; conceived and organised Design Modelling Symposium; coordinator of the Hybrid Platform (a cross/university interdisciplinary programme between UdK Berlin and TU Berlin); engineering award: Howard Medal; member of the Bavarian Chamber of the Construction Engineers, the Association of German Architects (BDA) and the International Association for Shells and Spatial Structures (IASS).
source: shapingspace.de, visited July 2019

[520] **IASS 2017 Hamburg**

[521] **Dr. Gregory Charles Quinn**
an architectural engineer interested in lightweight structures, structural design and form finding. Dr Quin worked as a structural engineer for Arup and as a freelance consultant for Atelier One and Bollinger + Grohmann. Currently Leader for Architectural Engineering at Swinburne University of Technology, Melbourne, Australia.
source: https://www.swinburne.edu.au/architecture-urban-design/about/people/gregory-quinn/, visited July 2019

[522] glass fiber reinforced polymer

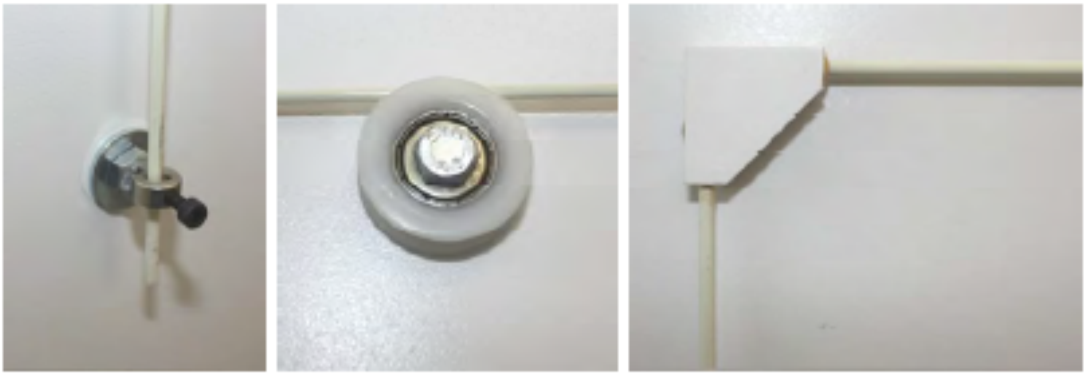


Fig. G1.12.1 Pin joint (left), rolling support (centre) and a rigid corner (right) in comb. with 3 mm GFRP rods

Interaction with the structure was mediated by touching it with a "magic lollipop" representing various loads (a gadget as seen on Fig G1.12.1), and immediately both internal forces as well as the reactions, which result directly from the deflections initiated by user, could be seen.

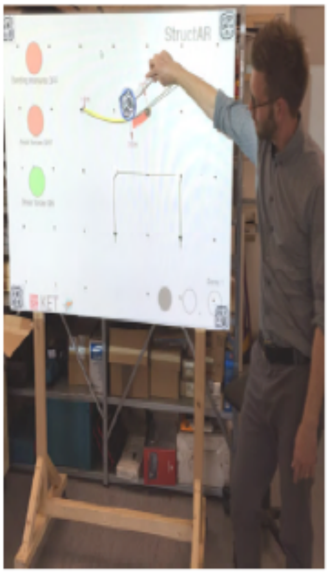


Fig G1.12.2 (left) — StuctAR prototype showing a user physically interacting with small structural frame made from GFRP rods. The physical objects are augmented by a projected overlay of internal forces from the same structural system.

Fig G1.12.3 (right) — A typical demo featuring four different portal frame systems. Proximity sensors were scripted to detect when the user’s marker is close to a particular portal frame thereby activating only that system and avoiding wasted processing power on inactive structural systems in the demo.

Interfacing between the physical objects and the digital simulation was done by tracking printed fiducial markers[523] with the help of a common optical webcamera.
Softwares used for the simulation were: Kangaroo dynamic relaxation (DR) solver and the Rhino/Grasshopper. StructAR works in 2D.

A natural extension of StructAR is virtual reality structures programme StructVR, which is described in paper from IASS 2018 conference[524].

The programme was originally created as a teaching tool, which would gave the user an opportunity of a virtual interraction with the structure together with the possibility of inflicting its deflection and then observing how the internal forces and reactions (directly rendered in real time) are distributed, and examining the structure's defformation pattern. The types of structures, for which the system can be used are for example: a portal frame, a truss, a bridge, a cantilever, a tower etc. There is a mode that allows the user to create his own structure from the scratch, interact with it, and then execute some modifications (e.g. to add or to remove some members), which would result in overall better structural performance.

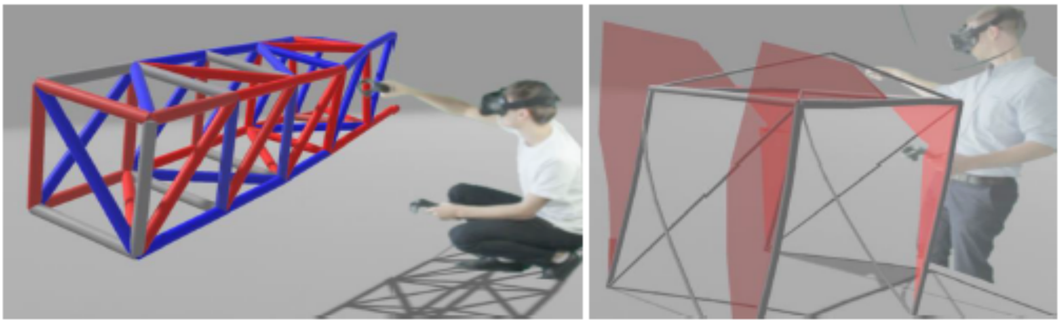


Fig G1.12.4 Working prototype of StructVR: sample structures
left: truss rendering axial forces
right: stabilised frame rendering bending moments under user-imposed deflection

The system is being successfully tested in the Department of Architecture at UdK Berlin.
Softwares used for realisation are: Rhino/Grasshopper, dynamic relaxation solver Kangaroo and Unity.
The prototype currently features the option of chosing out of two virtual environments : plain grey space and/or an actual physical room.

[523] A **fiducial marker** or **fiducial** is an object placed in the field of view of an imaging system which appears in the image produced, for use as a point of reference or a measure. It may be either something placed into or on the imaging subject, or a **mark** or set of marks in the reticle of an optical instrument.
source:wiki commons
[524] **IASS 2018**, Boston, Creativity in Structural Design *International Association for Shell and Spatial Structures*

For the switching on/off the display of internal forces, reactions and resetting or selecting models, there is a need for a user interface, which should be simple in order not to distract the participant. A radial menu has proven to be an optimal solution for operating the tool.

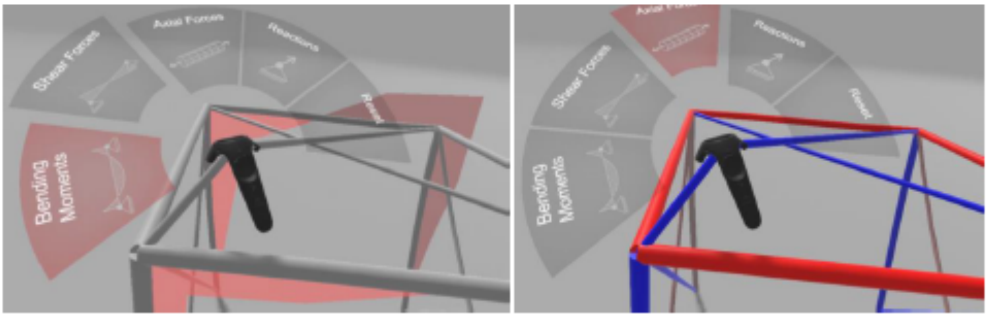


Fig G1.12.5 Custom virtual environment and visualisation of internal and external forces which can be deactivated on the fly. Left: bending moment, right: axial forces.

The experience of VR is personnal, therefore for an effective documentation of StructVR, there was a need to combine a video footage of a participant, which had to be superimposed on the digitally rendered scene.

There is already an early prototype of StructMR (mixed reality) gadget with further system enhancements planned.

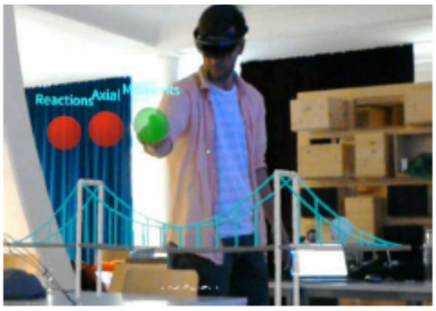


Fig G1.12.6 StructMR (mixed reality)prototype using the Microsoft Hololens and Grasshopper plugin Fologram: 3rd person perspective

Fig G1.12.7 StructMR (mixed reality)prototype using the Microsoft Hololens and Grasshopper plugin Fologram: 1st person perspective showing pinch gesture interaction with virtual simulation with bending moments (left), axial forces (middle) and reactions (right) .

G APPENDICES

G2 SE TUITION ACTIVITIES AND OPINIONS AT SELECTED UNIVERSITIES FROM THE CONFERENCE PAPERS

BALL STATE UNIVERSITY, MUNCIE, INDIANA, USA[525]

Prof. Chiuini sees the **main problems of structural courses at architectural schools** in the following:
- students struggle to understanding statics
- students show difficulties to apply mathematics whilst solving structural problems
- teachers do not have enough time to go through more complex matters
- structure courses and design studio are often seen as separate disciplines

He further expresses his view on **structural design**, which in his opinion is **not an exact discipline, but a skill requiring initial assumptions generated from experience**, and that students should be aware that often several iterations are needed to get to the final result.

According to Chiuini, **understanding of structural behaviour** can be also **significantly facilitated by the use of structural analysis software**, which allows students test alternative configurations, but on the other side warns about the **"black box syndrome"**, when students blindly use results produced by computer without actual understanding how they have been worked out. To reduce this effect, Chiuini **recommends the use of computer software** in structural courses only **after the students have been introduced to the basic structural knowledge in classical lectures**.

Chiuini devotes substantial part of his paper to actual **description of structural courses at Ball State University**, including referals to applied innovations (broadening the curriculum with statically indeterminate systems, introducing project into structural courses, using computer analysis), which he assesses as follows: the course has been overall enriched as students can learn about more complex structures like rigid frames (considered before as beyond students' abilities though very common in practice), and start seeing the structural part as more intertwined with the actual design. The use of the computer software proved to be as more efficient as far as the course organisation is concerned (3 terms of lecturing instead of 4, plus indeterminate structures now included), though only the most complex calculations are done by computer, and sizing the structural members is done by "traditional" way (formulas, calculators, pen and paper). The course is not focused on statics, but on the designing structural systems, and focus is put onto overall understanding of structural behaviour.
Chiuini also formulates open questions such as the need of thorough check of specialised software to assess its appropriateness, or finding the best way how to join structure courses

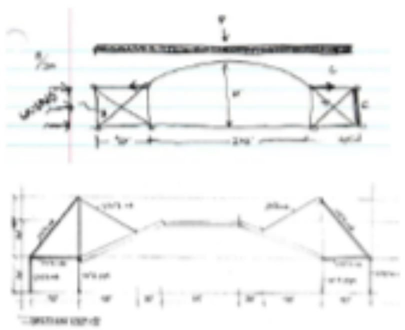
[525] CHIUINI (2006)

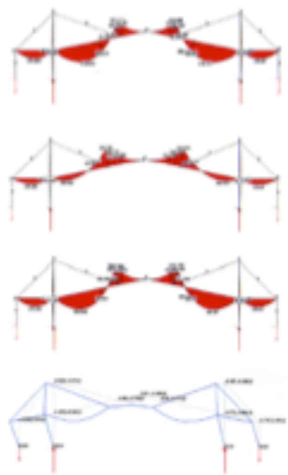
with the design studio, as he finds problematic for one tutor of structures to follow six to seven studio sessions with approximately 80 students.

Overall he summarizes the changes at Ball State University by paraphrasing Miesian quote: "Less is more" as " **less time can be devoted to toil on statics and calculations**, while the students acquire more knowledge about structural design and more understanding of how it is relevant to architecture.

Structures projects at BSU (concrete, steel, wood and masonry)

- students are asked to configure structural system in the context of their architectural design
- secondly, they analyze and dimension each structural member of the system and design the connections
- Chiuini suggests and requires students **sketching structural ideas before jumping straight to formulas**- Chiuini highlights **the importance of parallel lecture courses on materials and methods of construction** being given to students in order to successfully participate in structures project
- structural systems can be **further explored by the computer software *Multiframe***
- after that students **design the main structural members** (beams, columns, footings...)





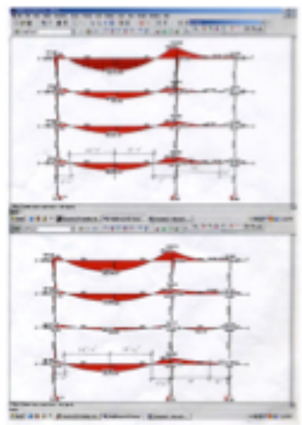


Fig. G2.1.1 Preliminary sketches for selection and configuration of a long span system

Fig. G2.1.2 Tests of alternative configurations with the same load using M diagram
Deflection diagram of long span steel systems

Fig. G2.1.3 Moment diagrams for full live loads and alternate live loads on beams

THE FACULTY OF ENVIRONMENTAL DESIGN, UNIVERSITY OF CALGARY, CANADA[526]

According the Soto-Rubio's observations, the **courses leaning on analytical techniques** are **problematic for students** with insufficient level of mathematical skills, and **stand-alone character** of the courses do not fully allow students to apply the knowledge to their projects.

For the above reason, he promotes **joining Structures with Design**, and further sees the potential in implementation "learning by doing" approach **- the use of physical models**, as he believes it deepens structural understanding. The **positions of structural systems and materials in architectural curricula** classifies as **very important.**

Following tasks are given to students:

Task 1: to design a 1m high tower structure, which would be able to support a brick. The base cannot exceed 30x30 cm. Students can choose any material and structural system. The tower must not display lateral deflection or torsion. (3 phases of the project: calculations, test loading, suggesting improvements).

Fig. G2.2.1 Samples of students' works / Task 1

[526] SOTO-RUBIO(2017)

Task 2: to design a cantilever structure that would be able to support an apple weighting approximately 1 Newton at a distance of 50 cm away from its base and 50 cm from the floor. The base should not exceed 30x30 cm (3 phases as for Task 1).

Fig. G2.2.2 Samples of students' works / Task 2

Task 3: to design and build a truss that can bridge 1m distance, and support a brick in the middle of its span (3 phases as for previous Tasks).

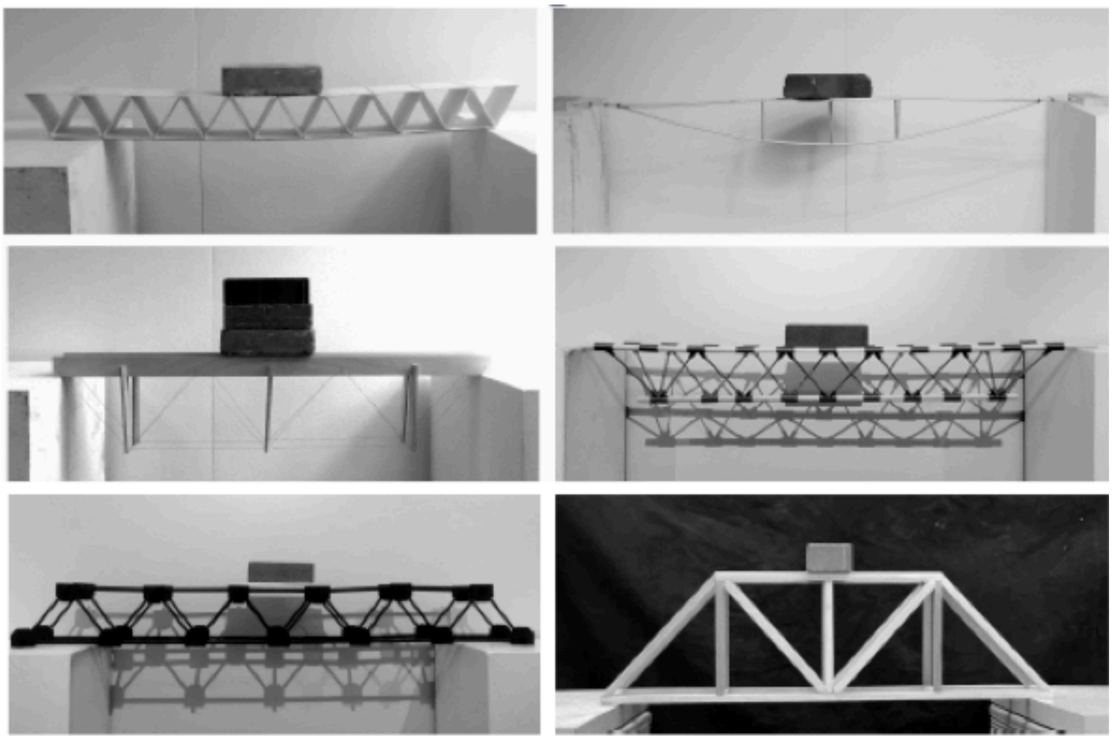


Fig. G2.2.3 Samples of student's works / Task 3

The aim of the excercises is to support and to improve students' perception of a relation between architectural design and structural performance

UNIVERSITY OF HONG KONG, CHINA[527]

The paper informs on **physical and digital models** that were used for teaching structures to architects at the **Chinese University of Hong Kong** around 2001. Some of the models were assessed as suitable for the explanation of structural concepts (therefore used for the class demonstrations or for the lab-based exercises), whilst other models - particularly visualisation tools - were seen as more appropriate to support the studio design process (as they allow structural investigations). Author identified **visualisation as an important part of the future architectural education**.

Longman listed particular **types of models** (physical/digital, or form/behaviour/interactive), and discussed their advantages vs. disadvantages.

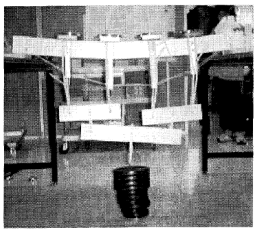


Fig. G2.3.1 Behaviour model/ Composite beam model under loading

Behaviour model project activity

- models exxagerating their response to loads have been assessed of more illustrative

(in order to reduce the moment of inertia either small section in relation to the length should be made or more flexible material should be used)

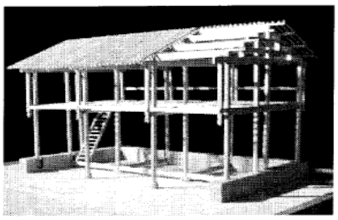


Fig. G2.3.2 Form model / Model of a Chinese timber frame

Form model project characteristics

- scale1:20, studio research, observing traditional forms
- measured during field trip
- traditional connections were made 1:5

[527] LONNMAN (2001)

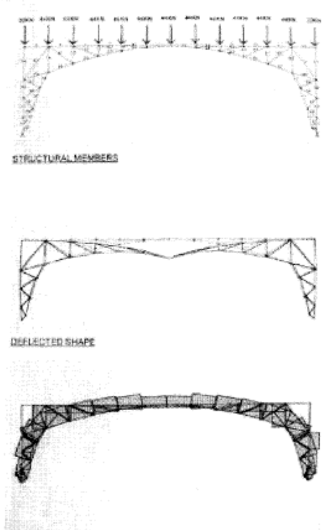


Fig. G2.3.3 (left) "less Roof" project / Load test
Fig. G2.3.4 (right) Truss frame analysis using Multiframe

"less Roof" project characteristics
- for students from years 1 to 3
- 1 week to construct according to the parametres given (size/given span, price, required load...)
- hand tools only,
- finally tested on specially made support fram

Lonnman sees **the main problem** concerning teaching structures to architects in "borrowing" an **engineering approach**, which is typically represented by an attempt to condense great amount of scientificaly-based structural theories, overall resulting in an oversimplified introduction into the problematics covering few basic elements. Students usually learn to design the main structural members (mostly of isostatic systems), but **do not understand structural systems and their behaviour**. Lonnman supports his argument by the opinion of Engel[528], who clearly distinguishes between the engineering and the architectural approach to teaching structures

[528] ENGEL, H.:***Perspective: Dilemma of architectural education***, in **Haider, G.** (ed.), ***Structures and Architectural Education: In Search of Directions,*** Ottawa, Ontario, Architecture Publications, 1974, pp.93-98. Proceedings of a Workshop held at Carleton University Ottawa, May 1972.

ILLINOIS INSTITUTE OF TECHNOLOGY, USA[529]

The Wetzel's Paper describes IIT's six years experience with introducing structural design assignment into the Year 1 Studio.
The "new" concept is based on the "Miesian philosophy" (to which the author refers to) emphasizing a rational approach towards structural design, for which knowledge on structural systems, spatial relations and material properties is vital.

Wetzel describes their attitude toward teaching structures as active, qualitative and empirical, focusing on understanding forces and mechanisms of resistance through organised experiments and through the guided large-scale model constructing, which promotes visual and intuitive approach.
One of the lecturers, Paul Endres also set up and developed a simple flexible software supported physical method of structural modeling, which depicted deformations and performance predictions of a computational model.

The course consists of three phases: in the **first phase, the instructions** are given, during the **second –investigative phase** students create models to demonstrate forces in structural members, and the **third phase** is devoted to the fabrication of large-scale structurally determined installations, part of which is also material investigation. Great emphasis is given to the knowledge of stress patterns.

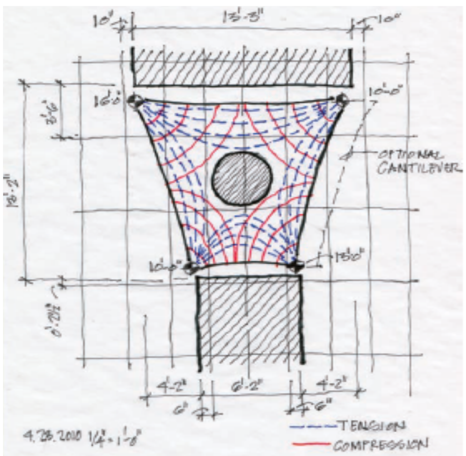


Fig. G2.4.1 Stress gradient diagram / example

[529] WETZEL (2012)


Fig. G2.4.2 (left) Reciprocal frame parabolic vault

Fig. G2.4.3 (right) Shoring removal and steel tube deformation for cca 30m span bridge

Fig. G2.4.4 (left) Installation from the milk crates

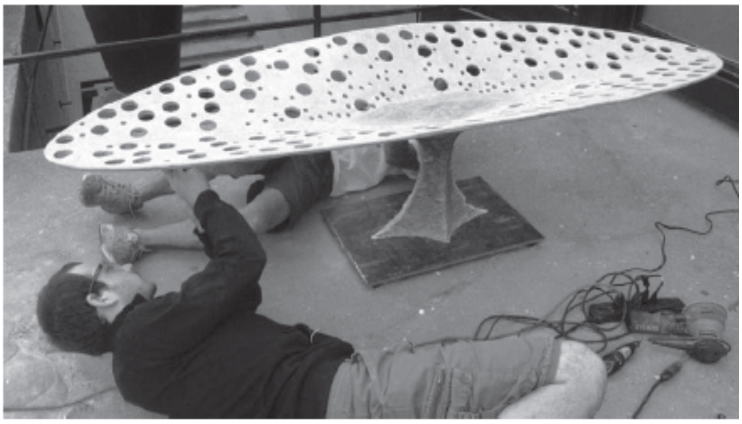


Fig. G2.4.5 (left) Quarter-scale model of a concrete cantilever shelf

THE FACULTY OF ARCHITECTURE, ISTANBUL KULTUR UNIVERSITY, TURKEY[530]

Learning by Doing“ Approach

The Building Mechanics course at the department of Architecture at Istanbul Kultur University is compressed fusion of statics and strength of materials. Compared to Turkish civil engineering programmes, where there are in total three semesters devoted to the problematics, architectural curriculum contains only the fundamentals of mechanics in the context of structural design. Statics focuses to understanding structural loads, forces and moments within structural members, whilst the strength part concentrates on the behaviour of deformable bodies. It includes concepts of stress, strain, mechanical properties of material and fundamentals of the design of beams, columns and structural connections.

An investigation monitoring students' motivation and structural understanding whilst applying methods of active learning has been conducted with 57 first year students as reported in the conference paper. At the beginning, the students were given an explanation about the concepts of forces, moments and equilibrium. Then a task was given to them, aim of which was to hold an object (weighing at least 150 grams) in the air without a direct support from the underneath. Allowed materials were: balsa wood, string and cardboard; the size of models was further limited by 50 cm span at largest. Both aesthetic and structural aspects had to be taken into account. To avoid design fixation via examples or guidance, given instructions were as vague as possible. They had two weeks time to complete the model together with a brief report describing the troubles they encountered and had to overcome during the process. At the end, students got the feedback highlighting the strengths and the weaknesses of their proposals.

[530] YAZICI & YAZICI (2013)

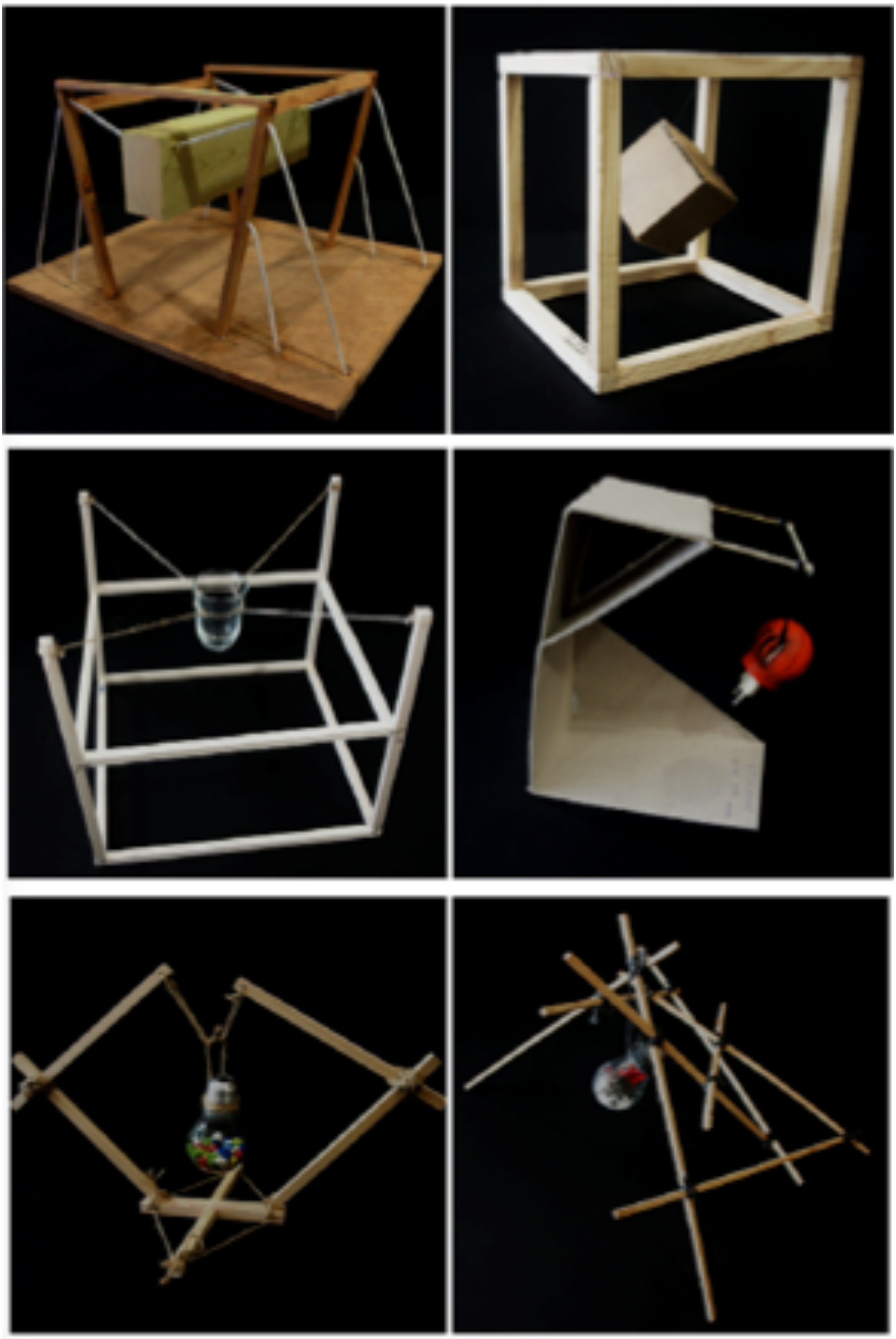


Fig. G2.5.1 a-f	Samples of students' works

UNIVERSITY OF OREGON, USA[531]

Plesums[532] describes an alternative approach to teaching structures with the help of structural models in 1974. His paper represents an interesting example on the development of this approach.

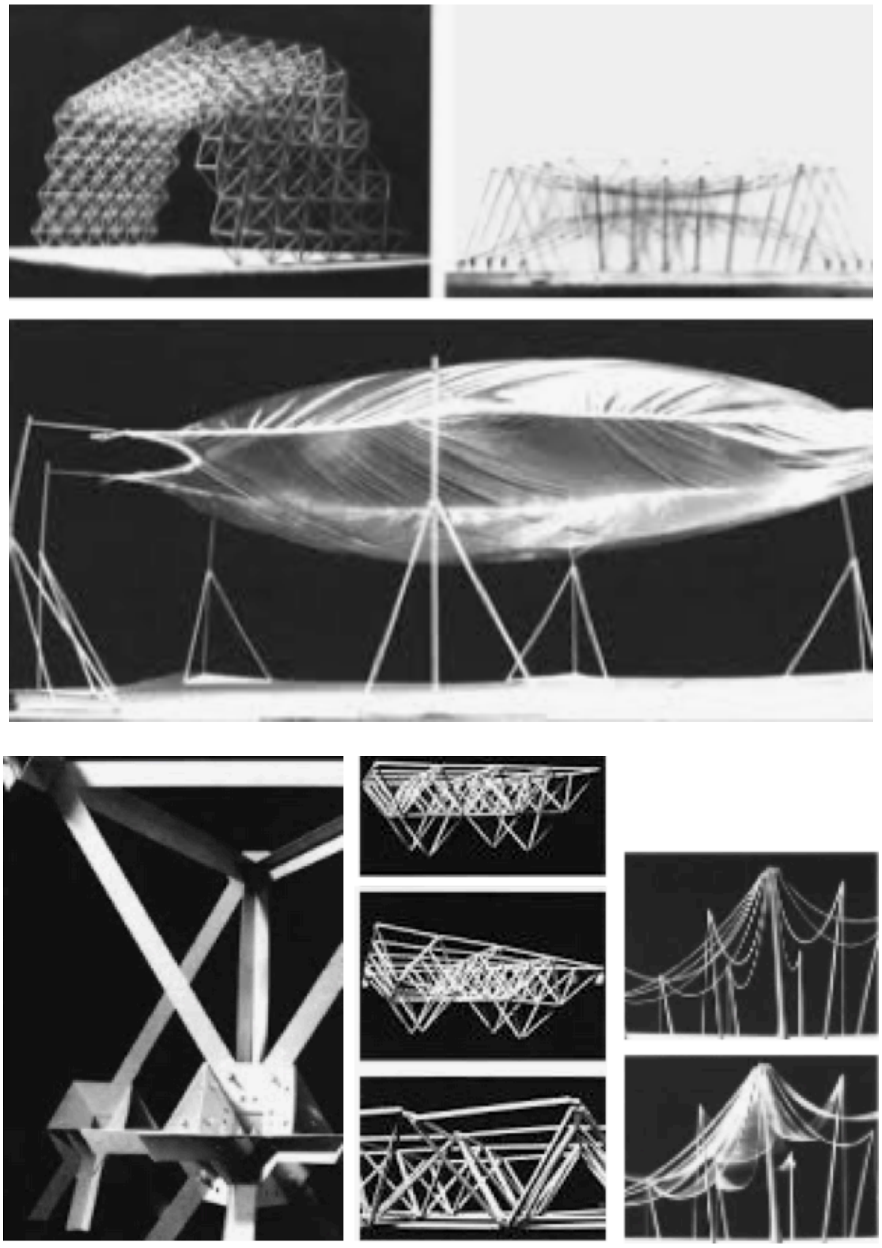


Fig. G2.6.1a-i Examples of the models used for teaching structural principles

[531] PLESUMS (1974)

[532] **Guntis Plesums (1933-**

Latvian and American architect and educator;

born in Latvia, 1950 came to the USA;

1961 BArch from University of Minnesota, 1964 MArch from MIT; worked for several architectural companies before moving to education; 1966-69 Rhode Island School of Design, Providence; 1969-95 professor architect University Oregon, Eugene; since 1980 also private practice; source: prabook.com, visited July 2019

JAUME I UNIVERSITY, CASTELLON, VALENCIA, SPAIN[533]

The paper presents two educational experiences applied to structural engineering courses at Jaume I University in Castello, Spain, as run by the Department of Technology. Hands-on learning was practiced as a combination of real structures and computer simulations. They were using parts from plastic toy building kit K'nex and balsa wood for creating structural models, and SAP2000 software for analyzis (replacable also with LARSA, STRUDL or ROBOT V6). The detailed description of experiments is within one of the earlier chapters of this thesis.[534]

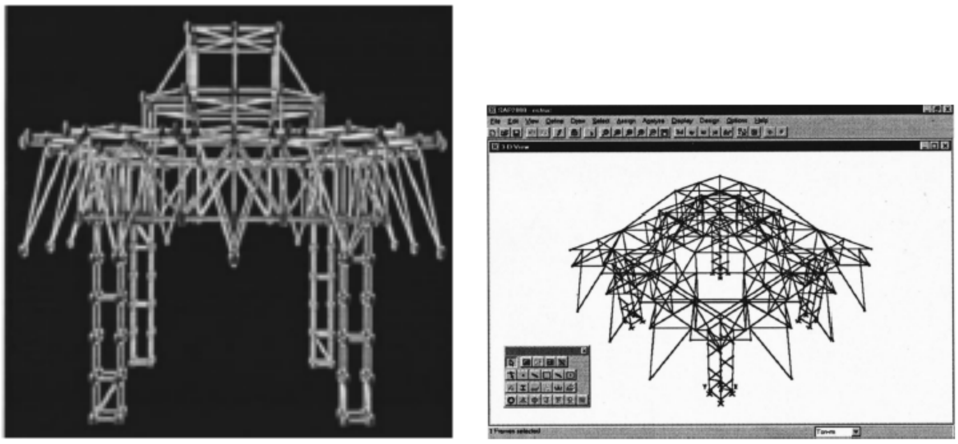


Fig. G2.7.1a-b Structure built with plastic bars (left) and modelled by computer (right) using SAP 2000

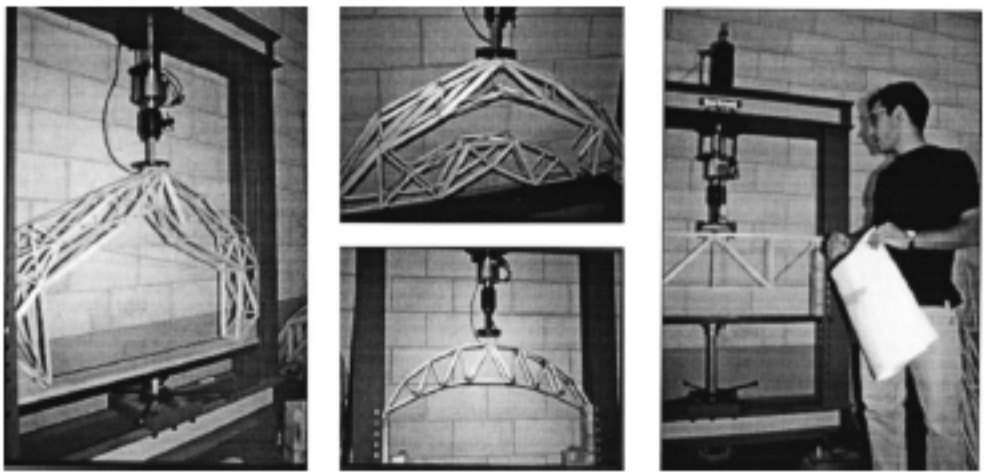


Fig. G2.7.2 Examples of balsa wood projects

[533] ROMERO & MUSEROS (2002)
[534] see p.69, Follow-up study on teaching methods/ Learning by doing

TAUBMANN COLLEGE OF ARCHITECTURE, UNIVERSITY OF MICHIGAN, USA[535]

Khodadadi describes an approach to teaching **Structures I** course at TCA by applying learning by doing approach. Structural experiments have been put together in order to demonstrate following topics: **Adding Forces, Moment of a Force, Equilibrium, Trusses, Arches, Elasticity, Centroid of Area, Shear Stress.**

In her opinion, there is a **need of learner of any age to get engaged with suitable activities** enhancing the basic course, and she supports it by citations from several renowned educational psychologists. She praises **class discussions**, for the attention may be paid to some facts (which come out in relation to the experiment), that might have been missed during lectures or may need further clarification. She also lists pottential **disadvantages** such as the need for accompanying explanation (lectures), lengthy duration, time consuming preparation of the instructor (though only before the first go), or the exercise not being fully suitable for groups for various reasons (e.g. students may misinform each other or some students may not be satisfied with this approach.

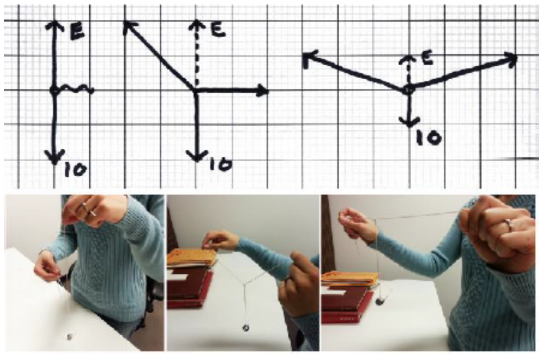


Fig. G2.8.1 Practicing "Adding Forces" with the help of a string and a nut

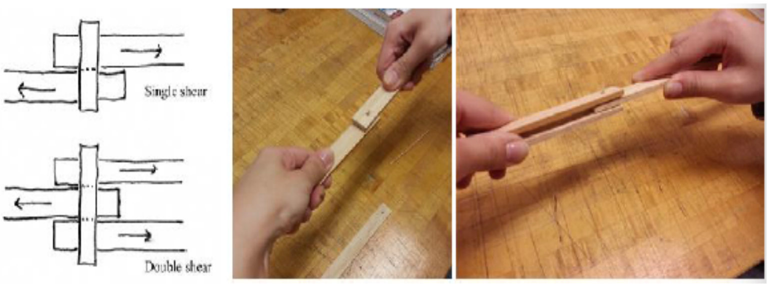


Fig. G2.8.2 Experiencing single and double Shear Stress

[535] KHODADADI (2015), EMAMI (2016)

Structures II course continues with more experiments covering following structural topics: **Buckling in Columns, Deflections in Cantilever Beams, Steel Beams, Flitched Beams, Continuous Beam,** and **Combined Stress**.

Fig. G2.8.3 Observing deflected shape on continuous beam with 3 or 4 supports.

Fig. G2.8.4 Observing combined stresses in beams: (left): flexure only, (middle): flexure + tension, (right): flexure + compression

Emami sees **small-scale lab projects as an effective strategy** complementing the main lectures. Iteration processes (loading structures to failure) can positively contribute towards grasping an intuitive comprehension of structural behaviour.

She also recommends **integrating Structures into the Design Studio** as an appropriate method enhancing structural understanding.

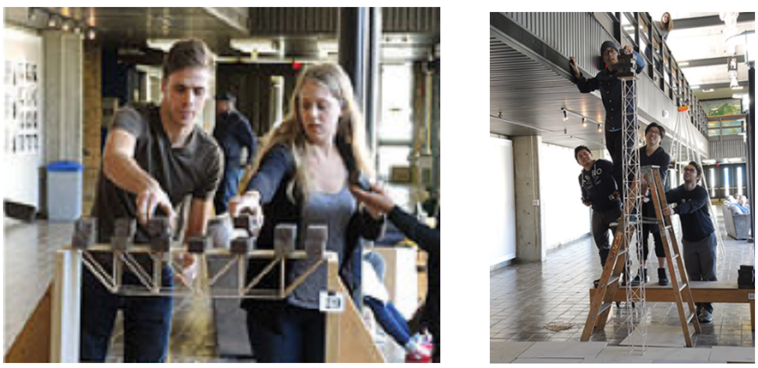


Fig. G2.8.5a-b Further assignments: bridge competition, tower design competition

MOSCOW ARCHITECTURE SCHOOL (MARCH), RUSSIA[536]

Tomovic brings into focus a **disintegration of an architecture into many separate disciplines**, which overlap and are often in a mutual conflict.[537] He observes „the archetypal image of the architect as an artist steadily sliding to the more engineering side of the spectrum" (especially in connection with the development of digital technologies), and sees a crucial role of an architectural education in **bringing an architect back to the leading position of the design**.

Tomovic **compares the three teaching systems**: **British** (internationally oriented, with a strong influence, experienced, progressive, preferring qualitative understanding to formalistic knowledge, strongly relied on the case-study approach and with connection to practice), **German** (very technically oriented, with a big share of SE in the architectural education), and **Russian** (conservative, following the traditional „beaux-arts" attitude, which perseveres despite several iterations of the Bologna proces).

MARCH introduces **programme based on British curriculum[538]** further **combined with German holistic approach to lecturing technologies[539]**.
Authors promote an approach to SE teaching, that would stimulate an „engineering way of thinking" , encourage a structural intuition, and bring graduate's practical needs into focus, and justify it by their own experience gained during collaboration with various architectural companies. Workshops and scale models see as a path to consolidate students' knowledge, promote using a specialised software, and highlight the importance of interconnecting technologies with other subjects from the very beginning. In their opinion the overal concept helps to overcome students' initial resistence to the engineering content of their curriculum and to see it as an integral part of their future praxis.

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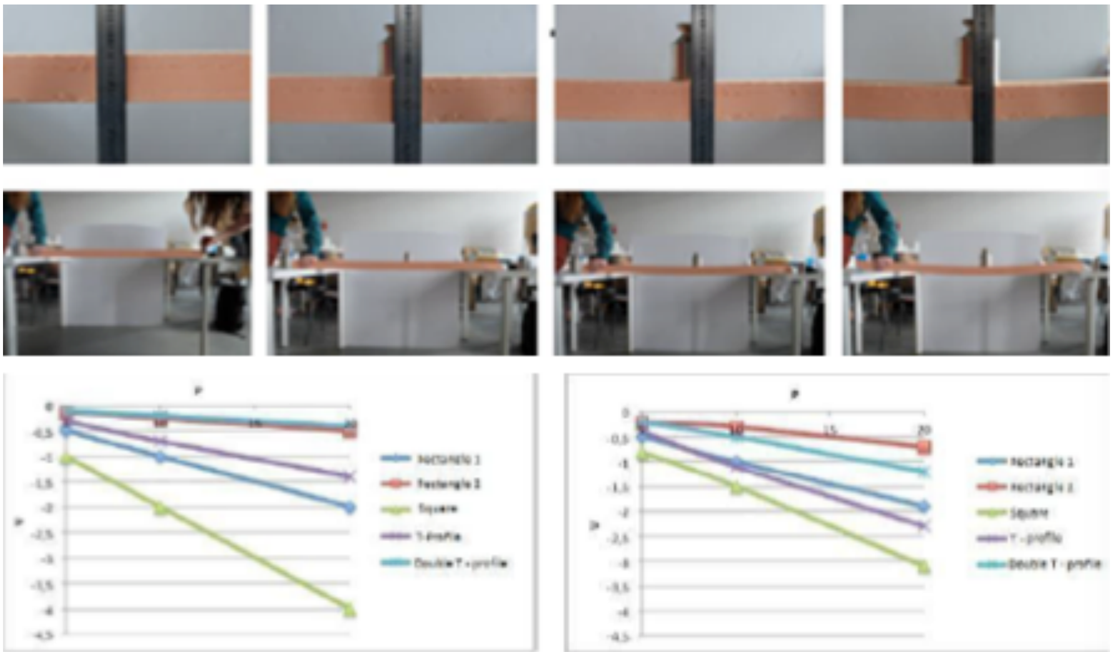
[536] TOMOVIC & SOBEK (2018)
[537] discussed in detail e.g. in: Sobek, W., Jahn, H.: ***Archi-Neering***, Hatje Cantz Publishers, 2000 or in: Building Arts Forum: ***Bridging the Gap: Rethinking the Relationship of Architect and Engineer***, Van Nostrand Reinhold, 1991
[538] created in cooperation with LMI CASS London, UK
[539] guaranteed by ILEK and Werner Sobek, who is responsible for teaching them at the University of Stuttgart



FORCE (g)	DEFLECTION (V)				
	RECT 1	RECT 2	SQUARE	T - PROFILE	DOUBLE T
5	-0,5	-0,13	-1	-0,3	-0,1
10	-1	-0,25	-2	-0,7	-0,2
20	-2	-0,5	-4	-1,4	-0,4

FORCE (g)	DEFLECTION (V)				
	RECT 1	RECT 2	SQUARE	T - PROFILE	DOUBLE T
5	-0,6	-0,2	-0,8	-0,4	[illegible]
10	-1	-0,3	-1,5	-1,1	[illegible]
20	-1,9	-0,7	-3,1	-2,3	[illegible]

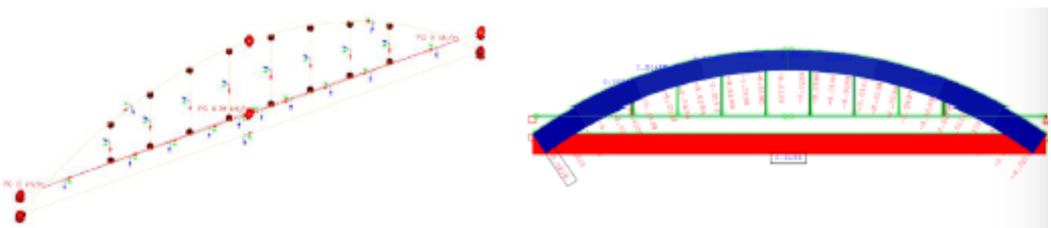


Fig. G2.9.1 (top) Deflection of a simple beam with various cross-sections (theory/ praxis comapred)
Fig. G2.9.2 (bot.) Timber workshop: building a bridge, loading to failure, investigating, software calculations

UNIVERSITY OF SARAJEVO, BOSNIA & HERZEGOVINA[540]

Authors describe the new approach towards teaching SE subjects at the Faculty following the Bologna Declaration, and compare it in the table below together with their opinion on strtuctural architectural teaching:

	OLD APPROACH	**NEW APPROACH**
Teaching hypothesis	Any field matter expert can teach	Teaching is complex and requires considerable training and effort
Knowledge	Transferred from faculty to students	Jointly constructed by students and faculty
Students	Passive subject to be filled by faculty's knowledge	Active constructor and discoverer of knowledge
Faculty's role	Classify and sort students	Develop students' competencies and skills
Context	Competitive/Individual	Cooperative learning
Method used	Drill and practice	Problem solving and collaboration

Fig. G2.10.1 Table depicting the differences between the "old" and the "new" approach

Year	Semester	Course name	ECTS	Lectures + exercises per week
1	I	***Statics of Architectural Structures 1***	3	2+1
	II	***Statics of Architectural Structures 2***	3	2+1
2	III	***Statics of Architectural Structure 3***	3	2+1
	IV	***Statics of Architectural Structures 4***	2	1+1
3	V	***Reinforced Concrete Structures 1***	2	1+1
		Wooden and Steel Structures 1	2	1+1
	VI	***Reinforced Concrete Structures 2***	2	1+1
		Wooden and Steel Structures 2	1	1+0
4	VII	***Reinforced Concrete Structures 3***	2	1+1
		Wooden and Steel Structures 3	2	1+1

Fig. G2.10.2 Modules and courses regarding Statics of Architectural Structures

- students should be **involved in the proces of structural design right from the beginning** of their studies, **and for the whole time** of their studies.
- good **knowledge of statics** is seen as **sufficient for finding an ideal form** of a structure, as mastering statics leads to understanding the flow of internal forces
- authors recount recurring **difficulties in explaining structural theories and concepts to architectural students,** who are predisposed to absorb **visual perceptions better than numerical ones**
- authors strongly oppose towards ruling out the numerical methods, they see the **solution in combining numerical and graphical methods**

[540] CAUSEVIC & MILJANOVIC (2014)

WROCLAW UNIVERSITY OF SCIENCE AND TECHNOLOGY, POLAND[541]

Theoretical lectures are accompanied by **exercises**, during which students make **various physical structural systems models**, which are loaded and their behaviour examined. They used different types of material and methods: e.g. wooden sticks and thin rope wires for tensile structures, Zometool system to make bar structures, and soap films to inspire the design of minimal surface structures.

Fig. G2.11.1 a-f Samples of students' works

[541] OGIELSKI et al. (2015)

SOUTHERN POLYTECHNIC COLLEGE OF ENGINEERING KENNESAW STATE UNIVERSITY, GEORGIA, USA[542]

Hong's paper recommends visual communication of structural concepts in architectural programmes, which he prefers to the mathematical one.

He considers current pedagogic approaches to teaching structural principles in arch vs eng. programmes as almost identical, and relatively unchanged for the past few decades, represented predominantly by calculations-intensive platforms, leading to limited role of students in the class limited, therefore being passive.

White-board-only teaching methodology associated with computations is according to him never effective or successful, as the students are discouraged, and therefore inactive. Insufficient knowledge of mathematics leads to their lack of confidence, low motivation, poor interaction, inadequate understanding, and low retention of structural principles.

Initiation phase: Visualizing SE Concepts "Open the mind"

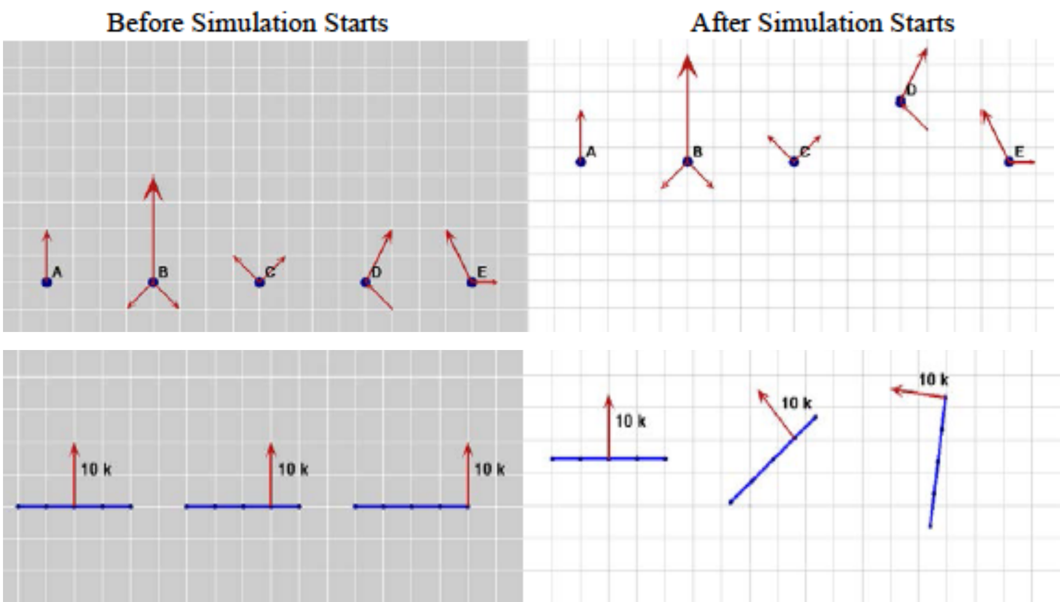


Fig. G2.12.1 Proposed activity ("race" of different sets of forces) according to Hong opens students'minds to engineering concepts (top)

Fig. G2.12.2 Moment of force and eccentricity concept mediated without mathematical formulas (bottom)

[542] HONG (2011)

Next phase: Changing Viewpoint "Second Intuition"

Fig. G2.12.3 Students are instructed to view the branch not as "falling down vertically", but as "rotating" around the point, which leds to developing of "structural eyes" to read the rotational equilibrium in architectural forms

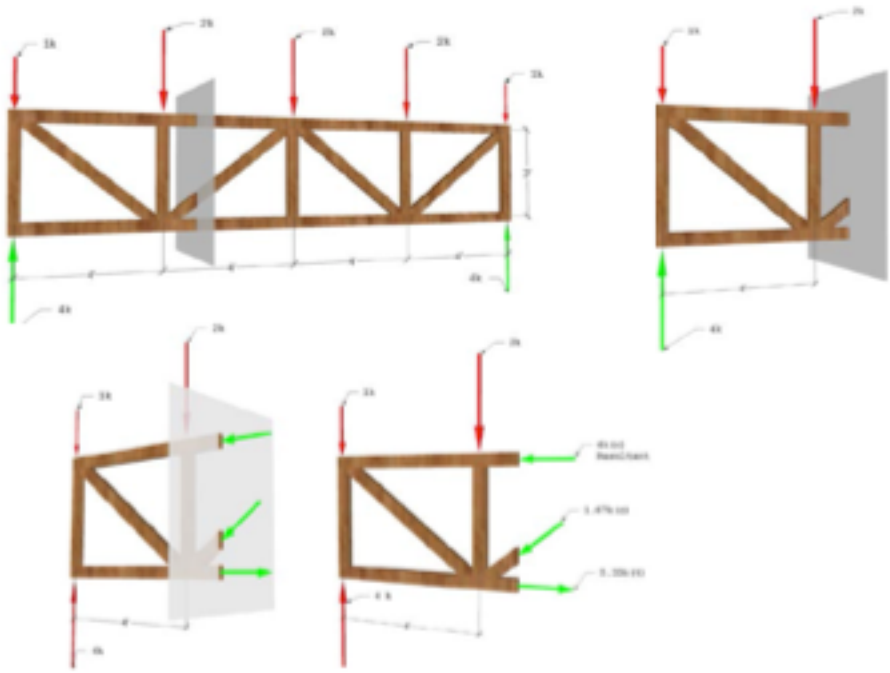


Fig. G2.12.4 The task of the teaching free body diagrams can be accomplished by viewing the structural system "hanging in the air" under the action of the external and the resulting internal forces in equilibrium

AUGMENTED REALITY FOR TEACHING SE RESEARCH, (COOPERATION OF THREE AMERICAN UNIVERSITIES)[543]

Oregon State University, Corvallis

Iowa State University, Ames

Texas A&M University, College Station

Turkan et al. (2017) states that students's deficits in understanding behaviour of structural parts in 3D context previously shown, has been caused by the **shortcomings of traditional** approaches, putting too much emphasis on the analyzis of individual structural members (and not providing holistic approach to the analyzis of more complex structures) resulting in many students not being able to see the relation between the static schemes and the real structures. They aim to illustrate **behaviour** of virtual structures **under different loading conditions** by the incorporating **mobile augmented reality AR and interactive 3D visualisation**.

Turkan's team (2018) second paper focuses on implementing AR into teaching process of structural design. Students have been asked whether they would like to be guided when solving structural problem, or whether they would rather explore the virtual structure via the means of application on their own, with inconclusive results, but a slight inclination toward individual explorations has been observed.

The application is called **iStructAR** and is for Apple and iPad and is currently tested in SE courses.

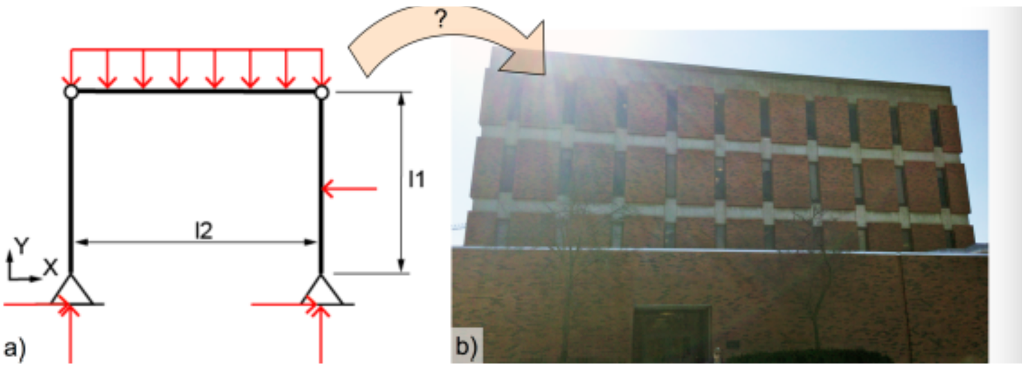


Fig. G2.13.1 Static scheme vs. the real structure, which in the opinion of the team students struggle to relate

[543] TURKAN et al. (2017, 2018)

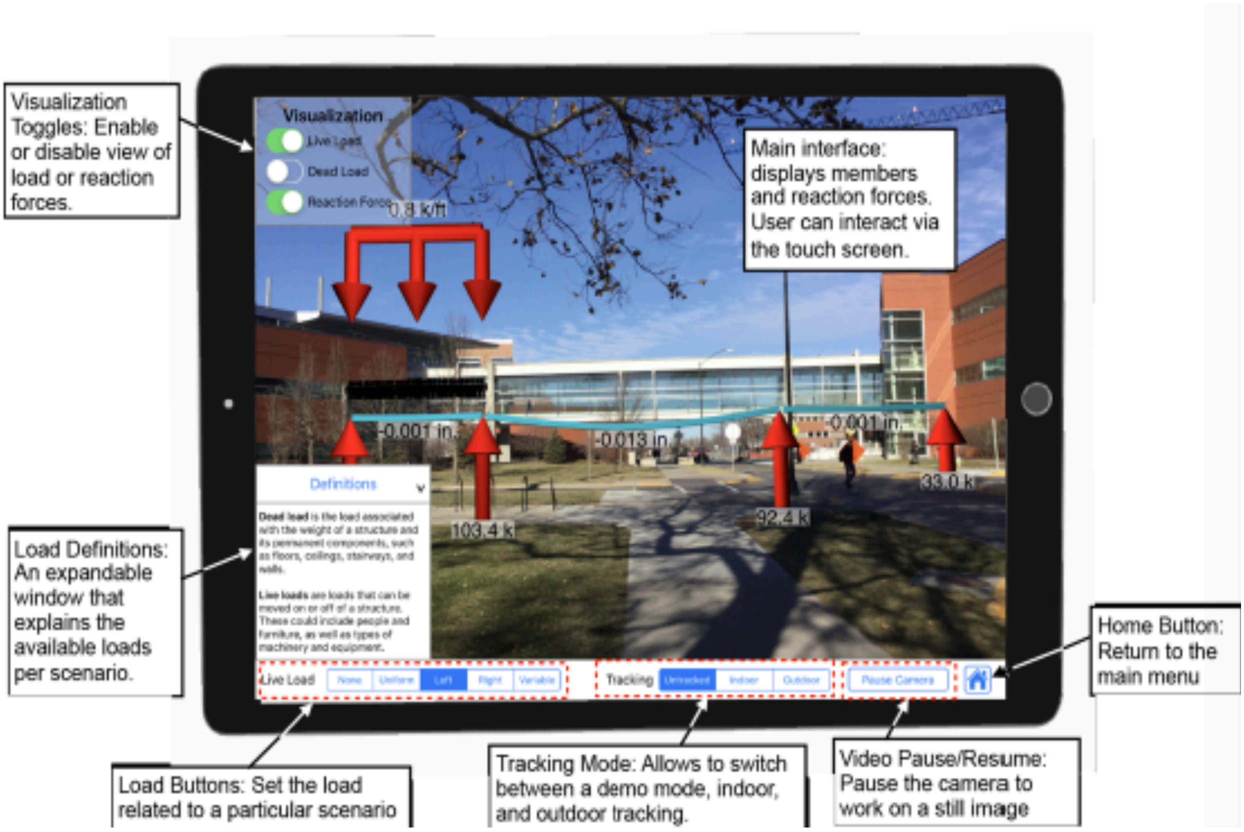


Fig. G2.13.2 The interface structure of iStructAR

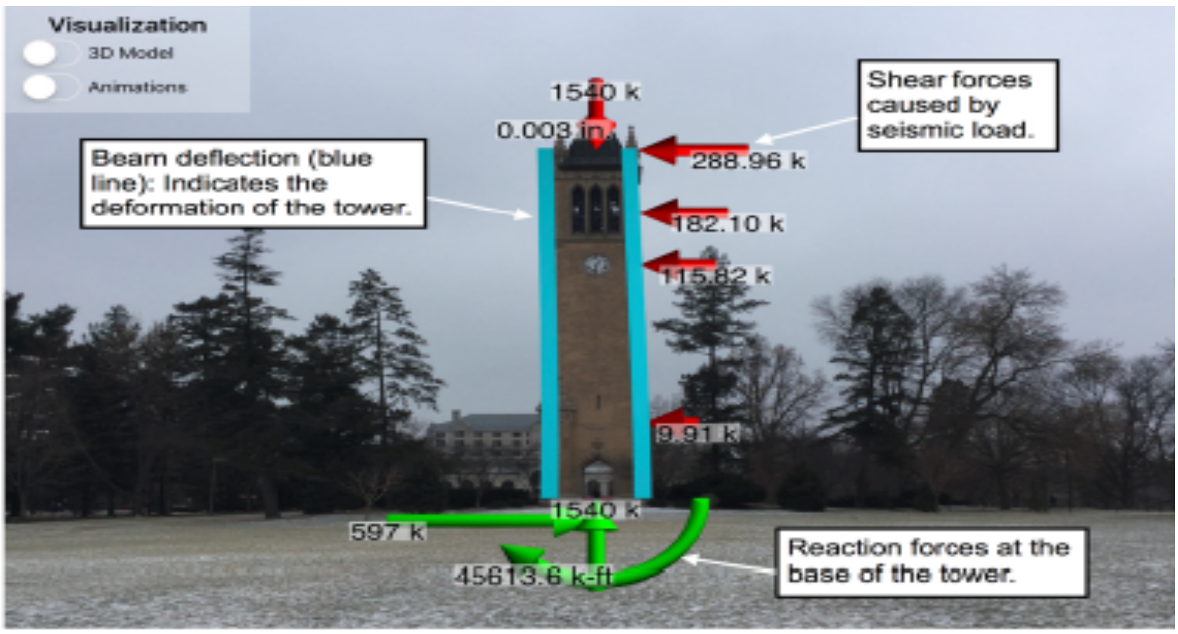


Fig. G2.13.3 Seismic load on a tower.
The example shows the reaction forces and deflection on modelled tower (beam member

G APPENDICES

G3 HISTORIC-LOGICAL TEACHING APPROACH (KURRER)

Short history of Structural Analysis (according to K.E.Kurrer)

Structural analysis provides a **set of scientific rules to more or less accurately model a structure and then to proportion each of its parts so that loads can be safely carried.** This includes the theory of structures, whose subjects are models and numerical methods, and the strength of materials relating to the dimensioning of structural members[544].

Using scientific rules in order to design the structures is relatively recent. Most of the ancient buildings and gothic cathedrals, which survived till today, were built not only without any calculation but also without any theory known today. For designing and building such structures rules of proportion developed through experience were used. Separation of an architectural and a structural design could be dated to the renaissance period.

According to Kurrer[545], the history of Structural Analysis could be divided into the following periods:

Preparation Time (1575-1825)

- Galileo in Italy introduced the concept of strength of materials (1638)
- Robert Hook (1629-1695) in England developed the theory of elasticity
- until the 18th century predominance of geometry and separate development of statics, strength of material and elasticity theories did not allow proper structural analysis of elements
- in the 18th century infinitesimal calculus found application in civil engineering (Leibnitz, Bernoulli brothers) and first engineering schools based on its application arose in France

Discipline Creation Period (1825-1900)[546]

- Henry Navier (1785-1836) in France created a scientific way to model and numerically analyse a structure using simple calculation tools and material properties (focused on hyperstatic structures)
- calculating methods for trusses (requiring large number of equations) were replaced by graphical analysis method developed by Swiss professor Karl Culmann(1821-1881) - essential for steel truss bridges, useful for isostatic trusses, less appropriate for hyperstatic ones

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[544] HEYMAN (1999), source: PEDRON (2006)

[545] KURRER (2002), source: PEDRON (2006)

[546] detailed information about the scientific principles established during the "new iron age" can be found in CHARLTON (1982)

- in the late 19th century Maxwell, Castigliano, Mohr and Muller-Breslau further simplified mathematical calculations for hyperstatic structures

Consolidation Period (1900-1950)

- invention of reinforced concrete (second half of the 18th century in Germany) lead to developing new theories in structural analysis: theory of frame structures (since 1915), theory of 2D structures- plates, shells, folded structures (since 1925
- in some cases, for hyperstatic constructions, the force method was replaced by the deformation method
- the deformation method was enhanced by the iteration method of Hardy Cross (1930)
- by the 1940, cold-formed steel parts began to be widely used in building construction and their problem of buckling investigated
- development of the plasticity theory (first papers at Berlin congress 1936), though idea of plastic design originated from Jon Backer (England, 1929)
- lower-bound theorem stated and proved by Gvozdev (Russia, 1936)
- fundamental theorems of plasticity theory developed by Prager's team(1949, Germany)

Integration Period (1950-1975)

- structural analysis completely revolutionised (arrival of computers, development of Finite Element Method in 60s and early 70s - main developers: Argyris (Stuttgart and London), Clough (Berkeley), Zinkiewicz (Swansea))
- first FEM programs (SAP, ADINA, ANSYS, NASTRAN, MARC…) were used only by specialists in computing centers, computers were large, slow and with no graphical interface
- modern digital computing allows non-trivial calculations concerning dynamics, collapse mechanism, materials and geometrical nonlinearities as well as computing ultimate loads

Diffusion Period (1975 until now)

- structural analysis totally revolutionised (personal computers in 80s, internet in 90s, large development in computer graphic)
- large variety of user-friendly FEM computer programs easily available, structural engineer needs to enter suitable model and specify loads

Methodology

based on historical development of structural mechanics

Contents, goals, means and characteristics of the historical genetic statics have been organised by K.E. Kurrer into the four stages as follows:

STAGE 1

Contents

- introduction to the statics of building structures
- qualitative encounter with the building
- elementary statics in the structural history context

Aims

- nature and objectives of the statics of the structure related to the strength theory, the construction and the planning disciplines
- clarification of the terms (on examples): structure, structural system, structural behaviour, support (function, quality, analysis), structural synthesis, static determinacy
- development of the ability to use the appearance of the building to derive the essence of the supporting structure
- quantitative recording of the equilibrium throught the historically logical comparison of the law of leverage with the parallelogram law of forces and the principle of virtual displacements (historical-logical comparison)
- static analysis of simple truss, understanding of the modeling of the truss to the statically determined articulated framework (historical and logical cross-sectional analysis)

Medium

- photographs
- sketching schemes
- different structural solutions (opposing)
- arithmetic and drawing tools

Characteristic

- inductive historical examples qualitatively discursive, interdisciplinary, analytical

STAGE 2

Contents

- elementary strength theory in the historic-logical context (Longitudinal analysis)
- quantitative analysis of structural elements like cantilever beams, beams up to two supports etc.
- analogy of beam and rope statics as well as definition of the support line (historic-logicallongitudinal analysis and structural analysis of historical vault structures including a comparison with current theoretical approaches
- qualitative confrontation with the structures according to its type (beam structures, vault structures, cable structures...)
- support structure elements (simple synthesis)

Aims

- quantitative recording of the stresses and formations in the beam structures
- structural analysis for easier (historic) timber structures
- load-bearing behaviour of structures, carrying qualty of the structures based on equilibrium and simple deformations
- construction of simple support structures (structural synthesis)
- role of the architect in conservation
- simple quantitative structural analysis for well-known historically significant buildings (e.g. St.Peter's Dome in Rome, load transfer in gothic church buildings)

Medium

- photographs
- sketches
- historical source material
- models

Characteristic

- inductive-deductive
- historic-logical
- exemplary quantitative-qualitative interdisciplinary discourse
- analytical-synthetic

STAGE 3

Contents

- confrontation with the real supporting structures
- principles of classical structural engineering
- intoduction into the statically indeterminate systems theory in a historical context (with special consideration of steel structures)
- structural principles of supporting structures and development of historic-logical structural systematics

Aims

- quantitative acquisition of conditions and lines of influence for a sheer force, deformation in staticaly indeterminate structures
- qualitative insight into the nature of stability problems (by discussing historical structural failures), the loss of stability due to the buckling
- modelling the load-bearing structure, classifying the supporting structure, determining the load-bearing behaviour
- comprehending the influence of changing parametres to the sheer force and deformation, developing the ability to judge
- acknowledging the "revolutionary"influence of reinforced concrete for the development of support structures (frames, plates, thin shells, wide-span arches) through examples from building history
- creating the conditions for imaginative modelling of structures

Medium

- photographs
- system sketches
- calculation tools
- diagrams
- simple calculations programs
- classic basic literature

Characteristic

- deductive-inductive
- historic-logical
- theoretical
- quantitative
- analytical-synthetic
- literary

STAGE 4

Contents

- quantitative encounter with the building
- simulation of engineering practice at preservation and securing of structures
- day to day planning for new buildings
- insight into the nature of non-linear theories of structural mechanics
- introduction into the structural analysis of roof structures
-dealing with technical regulations

Aims

- acquisition of design skills in the SE
- ability to evaluate possible safeguards for existing structures in need of renovation
- insight into the need of interdisciplinary co-working

Medium

- photographs
- damage reports
- construction surveys
- special literature
- design aids
- construction drawings
- program systems
- measuring devices

Characteristic

- inductive historical-exemplary
- qualitative, quantitative
- discursive
- interdisciplinary
- analytical, systematic
- anticipatory, experimental