

////////////////////////////////////

SIMPLE, COMPLEX, INNOVATIVE DESIGN EDUCATION AT CIVIL ENGINEERING

Sander van Nederveen, Felix Soons, Shahid Suddle, Hennes de Ridder
Delft University of Technology, The Netherlands
E-mail g.a.vannederveen@tudelft.nl

ABSTRACT

In faculties such as Civil Engineering, design is not a core activity. Core activities at Civil Engineering are structural engineering, structural analysis, mechanics, fluid dynamics, etc. Design education has a relatively small share in the curriculum, compared to faculties such as Industrial Design or Architecture. Against this background, our group has developed a design track within the Civil Engineering curriculum. This design track starts in the Bachelor phase with design fundamentals, continues with methods and skills for dealing with complexity, and culminates in the Master phase with innovative design approaches based on concepts such as living systems, parametric design, product development and life cycle thinking.

Keywords: Design Education, Civil Engineering, Integrated Design

INTRODUCTION

Design is a very important competence for many civil engineers. The importance of (integrated) design competence is recently confirmed once again by a platform of representatives of the Dutch construction industry, who act as a strategic advisory group for the civil engineering faculty [Keits et al 2009].

But unlike studies such as Industrial Design or Architecture, design is not a dominant element in the study curriculum. Only a small share of the study program is dedicated to design. As a result of this, space and possibilities for design education are quite limited. Against this background, our group has developed a design track within the Civil Engineering curriculum, which is presented in this paper.

This paper is structured as follows. First a general overview is given of the civil engineering study. Next the design education as given by our group is

described in more detail, starting at the first year of the Bachelor phase and continuing until Master electives and graduation work. Course goals, content and the motivation and ideas behind the courses are discussed. But also practical information such as student numbers and student effort are presented. Finally a brief reflection is given with a comparison to other studies and alternative approaches, and directions for further work are given.

THE CIVIL ENGINEERING STUDY - OVERVIEW

The Civil Engineering study consists of a Bachelor phase of three years and a Master phase of two years. The study attracts around 300 first year students each year.

The first two years of the Bachelor phase are the same for all students. In these years, a foundation is laid with subjects such as mathematics, mechanics, design methods and construction techniques. Students are introduced in the main themes Building, Water and Transport and in some non-technical subjects (TU Delft 2009).

Next, students can choose a minor program (half a year) and subsequently finalize the Bachelor phase with the remaining mandatory and elective courses of the third year. Overall, the Bachelor phase can be characterized as technical and broad, as it covers a wide range of subjects that are related to the different Master specializations. Design is present, but not dominant. In the next sections position, contents and form of design education at civil engineering are further described.

In the Master stage, students can choose from a range of specializations: Building Engineering, Hydraulic Engineering, Transport and Planning, Water Management, Construction Management and Engineering (CME) and six others. The role of design in the Master phase is of course highly dependent on the chosen specialization. Our group is closely

related to the specializations Building engineering and CME, therefore we will primarily discuss design education in the Master phase for these specializations.

POSITION OF DESIGN IN THE CIVIL ENGINEERING STUDY

As already said, the position of design in the civil engineering study is not as dominant as in studies such as architecture or industrial design. Design is just one of many disciplines that are taught at civil engineering.

Furthermore, design is not a typical civil engineering discipline. Many civil engineering disciplines (and courses) are technical disciplines with an analytic approach and a major role for calculations. The problems to be solved can be very complex, but they are well-defined and when you understand the approach and know how to execute it, you will more or less automatically find the solution of the problem.

In design however, problems are normally ill-defined and ill-structured, there are many solutions that can be right and many roads that can lead to a good solution. Also the top-down, trial and error nature of design and the multi-disciplinary nature are typically points of difference of design compared to the more technical disciplines.

But design and engineering are definitely not opposite disciplines. For example there is a large and exciting area between architecture and structural mechanics, including fields such as building technology, building engineering, structural design/analysis/engineering etc. Many challenging building projects in fact require a combination of design and engineering skills.

In the study program of civil engineering, both design and engineering courses are present, as well as fundamental courses on mathematics, mechanics, dynamics etc. But as said earlier, design is not very dominant, it is just one of many subjects. In fact, the design courses form less than 20 % of the curriculum in the Bachelor phase.

Moreover, at civil engineering most design courses work with groups. For many years already, the core of design education at civil engineering is formed by collaborative design projects, with group sizes varying from 4-5 to 20-30 students. Today, a

mandatory design project course is offered every year of the Bachelor phase; these three project courses form the core of design education in the Bachelor phase. Apart from these collaborative courses, individual design assignments are given occasionally in courses such as building design and infrastructure design.

The mandatory design project courses are among the few courses in which students must work together. As a consequence, many general skills such as presentation skills, report writing, project management, collaboration and teamwork must also be included in the design projects. Apart from that, there are a few competences that are also necessary for design projects and insufficiently dealt with in other courses, especially drawing, data collection and information management. As a result of this, there is even less time for the core design activities. An additional problem is that design projects are not always taken seriously by other lecturers. Design projects are associated with long discussions, coffee drinking, and a 7 (B) grade for everyone in the end. In reality, students are usually very motivated in design courses, work hard and spend a lot of time on their work. But it is true that the group results are rarely graded higher than 8 nor lower than 6.

CONTENTS AND FORM OF DESIGN EDUCATION AT CIVIL ENGINEERING

EDUCATIONAL APPROACH

The educational approach taken can generally be characterized as learning-by-doing. Most of the time students spend on design courses is spent on carrying out design assignments. And most of the contact time between students and lecturers is spent on instructions for the design assignment, presentation of the work that has been done and feedback on this work.

But also time is spent on lecturing design methods. Compared to faculties such as architecture, there is quite some interest in design methods, both from students and from lecturers. This could be due to the more analytical nature of the civil engineering domain: civil engineers tend to look for methods that provides them a grip on the design problem.

Examples of design methods that are discussed are

multi-criteria-analysis and systems engineering methods.

THE START: DESIGN FUNDAMENTALS

In the first year, one mandatory design course is given of 7 ECTS (196 study hours). In this course students work in groups of 8-10 persons on a design project. In this course the emphasis is on design fundamentals. Technical details, financial elaborations, etc. are not required.

For many students it is the first time ever that they do a design project. At this stage it is important to address the fundamental characteristics of design: the top-down, trial and error nature of design, the multi-disciplinary nature of design and the fact that many solutions can be right.

Furthermore the elementary design cycle is introduced: analysis, synthesis, simulation, evaluation, decision. Concepts such as requirements, functions, stakeholders, value, risk, RAMS parameters, verification and validation, etc. are explained in the context of the elementary design cycle.

CONTINUATION: COPING WITH COMPLEXITY

In the second year, again one mandatory design course is given, now 5 ECTS (140 study hours). Students work again in groups of 8-10 persons on a design project.

In the second year, the assignments become bigger and more complex. Aspects such as constructability, safety, finance and risk management become important.

In the third year, the third mandatory design course is given, again 5 ECTS (40 study hours), but now students must work together in groups of 20-30, which means they have to organize themselves rigorously. Project decomposition and interface management become predominant. In this kind of projects systems thinking and a systems engineering approach is essential. The assignment in the third year is of course somewhat bigger and more complex than the previous courses, and technical elaboration of specific aspects is required.

CULMINATION: INNOVATIVE DESIGN APPROACHES

In the Master phase of the study, students specialize and course groups become much smaller. Typically

students follow courses for about 16 months and do graduation work for 8 months.

Master students in Building Engineering have a mandatory project course High Rise Buildings (11 ECTS, 308 study hours). This course, led by the Faculty of Architecture, has a truly multi-disciplinary setup. Groups consist of 6-8 students and each student is responsible for one of the disciplines: architecture, structural engineering, façade & building systems, BIM, sustainability and project management. The high rise project is a very challenging course. Yet the view on design projects is similar to the Bachelor courses discussed above. On the other hand, in courses of the Master track Construction Management and Engineering we also introduce alternative approaches to the common approach used in the Bachelor projects and in most projects in practice. Normally it is assumed that design and construction projects are one-of-a-kind projects: for every project designers start again from scratch, elaborate structures, calculate columns and beams that have been analyzed already countless times before, re-invent many wheels and hardly apply lessons learned from earlier projects.

In our view, the construction industry cannot continue to work like this. Furthermore we think that also our students must learn alternatives for this ineffective and inefficient way of working. Therefore we use the final stage of the study to present innovative design and product development methods.

As a starting point for this, we use a paradigm shift towards the development of living buildings and construction works in changing contexts, starting from product families (De Ridder 2006) (Van Nederveen et al 2010). Buildings and construction works are no longer seen as static structures that are built once and never changed thereafter. Also it is acknowledged that the (physical, social, etc.) context of buildings is changing all the time. Finally, we see that industrial concepts such as product families, modular structures, product service systems, etc. will inevitably change the construction industry. In order to enable this paradigm shift, knowledge is needed on subjects such as building information modeling, parametric design, building simulation, differentiation of life spans of building components, life cycle management, etc.

Some of the concepts described above are difficult for students to understand. But we see it as our mission to educate these young people that are needed in the near future for the necessary innovation of the building and construction industry.

Van Nederveen, S., Beheshti R., De Ridder, H., “*Supplier-Driven Integrated Design*”, in *Architectural Engineering and Design Management*, 2010, Volume 6, p 241-253, 2010, ISSN 1745-2007.

TU Delft (2011), *BSc Civil Engineering*, <http://home.tudelft.nl/en/study/undergraduates-bachelors/undergraduate-programmes/civil-engineering/>

DISCUSSION AND FUTURE WORK

In this paper a design education track is presented that starts from design fundamentals, continues with increasing complexity and culminates in innovative design approaches based on industrial concepts and taking into account the dynamic context of construction projects. Although the programme works quite well as it is, there are several possibilities for improvement:

- In the Bachelor phase, the relationship with other courses is not very strong. Ideally, students use all the science and engineering knowledge they have gained in other courses and apply it in the design projects. In practice this does not really happen; there are sometimes signs that students still regard the different courses as totally different worlds.
- In the Master phase, the emphasis is on innovative design approaches. But most of these approaches are not yet “proven technology” or “proven practice”. Part of the concepts is still in a research stage. The result of this research as well as experiences in practice need to be applied in order to improve the Master courses. This is especially the case for the latest developments in supporting technologies for design such as Building Information Modelling and Parametric Design.

REFERENCES

Keijts, L.H. et al (2009), Keijts, L.H., Van Den Berg, D.J., De Quelerij, L. and 24 others *Convenant Steuncampagne*, (collaboration agreement between CiTG Faculty and construction industry representants, confidential), December 2009, Appendix 4, p 18.

De Ridder, H., Soons, F., Voskamp, R., *Inleiding Integraal Ontwerpen, Deel A*, Lecture Notes CT 1062, TU Delft, 2010.

De Ridder, H., Suddle, S., Soons, F., *Integraal Ontwerpen*, Lecture Notes CT 2061, TU Delft, 2009.

De Ridder, H., *Systems Engineering*, Lecture Notes CT 3061, TU Delft, 2009.

De Ridder, H., Het living building concept, een weekend perspectief voor de bouw, Gouda 2006.