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Interdisciplinary methods in architectural education

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ABSTRACT: In this article, the authors present an interdisciplinary approach to architectural education with an emphasis on the co-operation between two groups of students: of architecture and of civil engineering. The co-operation between the students of architecture and of civil engineering was tested during the experimental course ProtoLAB delivered in the Faculty of Architecture and in the Faculty of Civil Engineering at Wrocław University of Science and Technology (WUST), Wrocław, Poland. During the course, students from both disciplines were asked to co-operate in the whole process, starting with the conceptual design and finishing with the shop drawings, and the construction of a prototype. The evaluation of the course showed how students with different backgrounds learn from each other new skills, and also the advantages and the weaknesses of such teaching. At a general level, the study shows that the co-operation between students of architecture and other related disciplines supports their mutual understanding between different fields, and hence strengthens a positive relation between them at an early stage of their careers.

INTRODUCTION

The profession of an architect can be compared to a film director or an orchestra conductor. They both co-operate with people with different qualifications in order to deliver one coherent piece of art. Since architecture is applied art and its creations remain for decades and longer, architectural creation must be governed by many principles. One of the basic is the law of physics. This is why architecture and construction were inseparable disciplines until the mid-18th Century, when the first schools of engineering were created. Since then, the co-operation between architects and engineers evolved from confrontation, in the 19th Century, to close collaboration in the first half of the 20th Century, when it was inspired mainly by modernists.

One of the greatest promotors of close co-operation between architects and structural engineers was Ove Arup, a structural engineer, who in his philosophy of *total design* was persuading engineers that a building is not only a structure, and it could be something more than stability and structural calculation. On the other hand, Arup encouraged architects to look at the design as a whole and to respect the contribution of engineers to the design. Arup stated that *Design, costs and organisation of the building site are not three separate operations, but need to be considered as one* [1]. The other great figures in the world of architecture and structural engineering who linked the two disciplines were Felix Candela, Pier Luigi Nervi, Heinz Isler, Otto Frei, Mamoru Kawaguchi or Santiago Calatrava in whose works the beauty comes from the *honest architectural expression of the structure - and structural expression of architecture as well* as Kawaguchi expressed his design philosophy [2].

Despite the efforts made for co-operating between architects and engineers, there is still a significant gap between these professions. Cody Thrape, director of the Thrape Engineering Group, indicates that both architects and engineers have weaknesses. One the one hand, architects lack structural understanding, they underestimate the role of engineers, wait too long before seeking advice and have a low interest in collaboration. On the other hand, engineers' interest in innovation is reduced, and they have fewer creative visions and lesser engagement in design ideas. This situation is a source of frustration for both parties [3].

The realisation of an architectural project is always a collective effort and architects must be equipped with the appropriate tools and skills necessary to finalise their work successfully. The basics of these skills are acquired during their academic education and developed in the subsequent stages of their careers. As stated by Schneider-Skalska, through their academic education, architects should acquire knowledge from disciplines like law, sociology, psychology, civil engineering, geodesy, environmental engineering and economics, and should be equipped with skills such as, creation, presentation, mediation, co-ordination, management and even pedagogy [4].

In this context, the aim of this article is to present the skills acquired by the students of the Faculty of Architecture (FA-WUST) and the Faculty of Civil Engineering (FCE-WUST) of Wrocław University of Science and Technology during the ProtoLAB course, as an example of interdisciplinary experimental education. The ProtoLAB course is a testing ground where the co-operation between the two disciplines has been explored in terms of communication, work organisation, mutual learning, mutual inspiration, ability to find one another's roles in the process of the project development, and respect for the other discipline. The main research aim of this article is to provide an empirical evaluation of the benefits, potentials and risks of interdisciplinary co-operation between architects and structural engineers in higher education in terms of mutual learning and understanding.

INTERDYSCYPLINARY EDUCATION OF ARCHITECTS WORLDWIDE

In the higher education system, architecture and structural engineering interweave, but they stay separated disciplines. Students of architecture learn some basics of structures, while students of civil engineering receive simplified theoretical knowledge of built environments. In order to bridge the gap between these disciplines, new educational programmes have been established in which architecture and engineering are taught simultaneously. Those programmes, such as the architectural engineering (AE) studies, resulted in a double diploma: engineering approach to architectural design. The AE is a programme where the interaction between various disciplines, such as architecture, structural engineering and building systems is used during the process of project development as a holistic approach to design, construction and operation. The acquired skills allow graduates to perform the architectural and structural design, as well as the service engineering of a project.

The oldest AE programme was established at the PennState University in 1936. Currently, there are more than 60 AE programmes worldwide [5]. While at some universities a greater emphasis is put on architectural design and technology (Delft University of Technology - TU Deft), at others the focus is on structural engineering (Aarhus University) or it is distributed between several disciplines (PennState University). However, due to the need of multidisciplinary knowledge acquisition in architectural education and to time constrains, AE studies may narrow the education of future architects by excluding the artistic and aesthetical, social, historical and contextual aspects. Therefore, some of the AE programmes do not provide the title of architect, and thus the graduates are not authorised to perform independent designs. Nevertheless, the success of AE studies reveals that interdisciplinary education, in which architecture and structural engineering have a common purpose and are coordinated towards a common higher objective, seems to be crucial.

Next to AE studies, interdisciplinary education can also be obtained through interdisciplinary courses, where students of architecture and civil engineering (and also other building industry related disciplines) closely co-operate on one common design assignment. For a comprehensive understanding of a design and the development of an architectural creation in interdisciplinary co-operation, the education system should include the whole process from the idea to its implementation. An example of such an approach is the BuckyLab course from the AE programme in the TU Delft.

The BuckyLab is a group of courses that includes *design*, *material science*, *structural mechanics*, *computational aided design* and *production technology*. During this course, students of architecture create the ideas of innovative façades, sun shadings and acoustic systems, pavilions or emergency structures. Then, students develop their ideas and this requires extensive material and structural research, as well as prototyping. The last two weeks of the course are dedicated to production, for which students construct the final prototypes by means of professional building tools. In the end, the prototypes are subject to final tests. The BuckyLab course gives an opportunity to challenge students through out-of-the-box thinking, through creating innovative products and through using the design and prototyping methodology [6].

Another course, where the development of a certain building product is being invented, researched and prototyped, is the Experimental Façade Technology at the Technical University of Darmstadt. This course integrates students from the Faculty of Architecture and from the Faculty of Civil Engineering. The assignment of the course concerns inventing façade elements created with different systems and materials, such as steel, clay, concrete or cardboard. Students work in interdisciplinary teams and do the work from the initial design to the final prototype. Prototyping is organised in steps, e.g. every week students work in the workshops on their projects.

THE PROTOLAB COURSE - A LABORATORY FOR INTERDYSCYPLINARY STUDIES

The ProtoLAB course is an optional experimental course for Master students taught in the FA-WUST and the FCE-WUST. The main aim of the course is to provide students with interdisciplinary knowledge in the field of methodologies of architectural design and building structures by completing the entire design process from concept to realisation. The main aim is achieved through creative co-operation in interdisciplinary teams, which are focused on solving project related problems, and hence on acquiring new skills by mutual learning. The additional aims are to gain understanding and respect of the other discipline, to find one's role in the project process by carrying out assigned tasks, and to acquire the ability to use construction tools and to work with materials.

The inspiration for the course was taken from the courses taught at other European universities, such as the BuckyLab available at the TU Delft and the Experimental Façade Technology at the TU Darmstadt. Although prototyping is a crucial part of the above-mentioned courses, and it is also a significant part of the ProtoLAB course, this aspect is omitted in this article, as the main focus is put on interdisciplinary co-operation itself.

The ProtoLAB course runs for 15 weeks and it is available for maximum 15 students from the FA-WUST and 15 students from the FCE-WUST. The course is taught by three teachers: an architect from the FA-WUST, a civil engineer from the FA-WUST and a civil engineer from the FCE-WUST. The association of teachers with different backgrounds gives the opportunity to provide a comprehensive knowledge in design, building technology and structural calculations. Students from both disciplines are asked to co-operate in mixed teams from the beginning until the end of the course. The emphasis is put on group co-operation. The topics of the course concern small scale architectural structures, such as pavilions [7].

The proposed methodology of the course draws on the Methodology for Product Development in Architecture, created by Mick Eehkout (professor at the TU Delft) [8]. According to this methodology, the process is divided into several phases, for which consecutive steps determinate the design decisions:

- The *conceptual design* phase;
- The *project development and research* phase;
- The *production* phase.

In the first phase, teams of three to five students from both faculties work on the conceptual part of their projects. This phase lasts for about five weeks, and the main focus is on the architectural design and structural stability. Students elaborate the design with preliminary decisions of the chosen materials, the structural system and the production methods. The size, shape and the functionality of the architectural object is being prepared. At the end of this phase, each of the teams presents its concept. The projects are presented by means of plans, sections, 3D models, visualisations and physical models. Next, the discussion and the vote for the best idea takes place. The teachers give their opinions on the architectural quality, feasibility and the structural solutions of the projects. However, they do not participate in the voting. The best and most likely to be built project is chosen for further development.

After the selection, the second phase of the course starts. Students are asked to rearrange themselves into working groups. There are 5 to 8 working groups, depending on the course assignment. Each of the working group focuses on a different aspect of the project:

- The *general design* group takes care of the overall design. In this group, at least one person should come from the winning project team from the first phase.
- The *structural design* group is responsible for structural calculation. The group gives feedback about the structural stability and the details of foundation, as well as the connections between elements of supporting system.
- The *material research* group deals with the chosen materials, their properties, but also price and availability on the market.
- The *managing* group, whose role is the management of project development and construction. This group contacts sponsors and suppliers, and prepares the overall budget. It is suggested that at least one person from the winning project team takes part of this group.
- The *exhibition design* group deals with the content of the exhibition and its exposition. At least one member of the group is a co-author of the winning concept design.
- The *promotional and PR* group takes care of the promotion of the project, contact with sponsors, preparation of visual identification, flayers, posters, invitations for the opening day and a Web site. Moreover, the group works on the events, which might be associated with the pavilion.
- The *special* groups - if the project requires some extra elements, such as interior equipment or urban furniture those groups design and elaborate them.

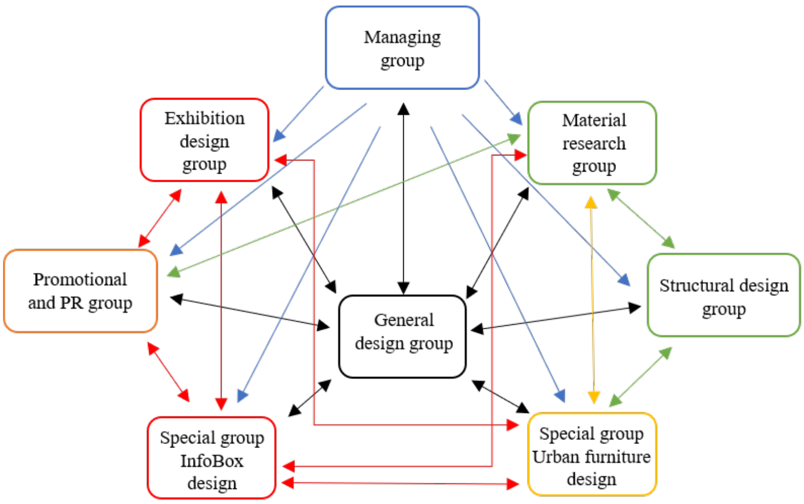


Figure 1: Interactions between working groups during the second phase of the ProtoLAB, edition 3.

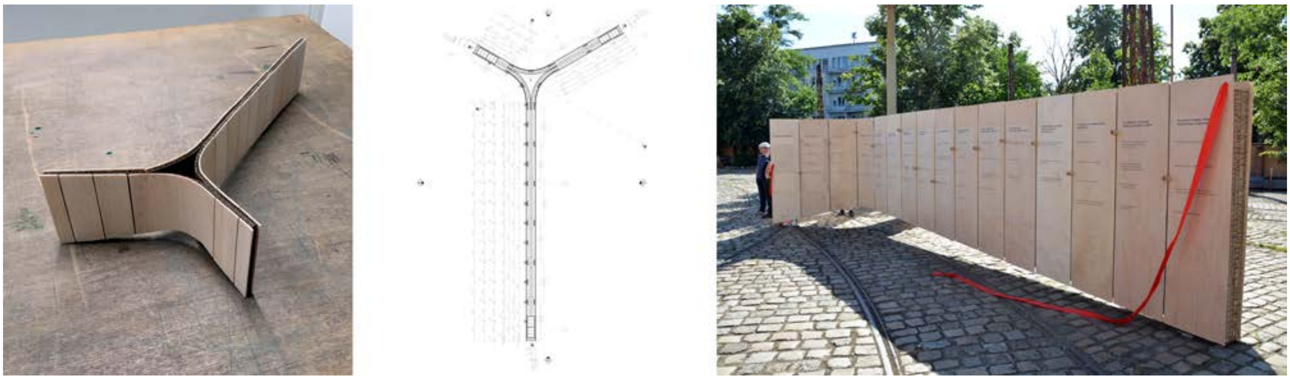
In every working group there are students from both the FA-WUST and FCE-WUST. The co-operation between groups has a matrix structure (see Figure 1); however, the *general design* group has a leading position in design-directed decision making, and the *managing group* organises the overall development and production process, and decides about the schedule and budget. Other groups co-operate with each other, exchanging their knowledge, ideas and findings. Some groups co-operate closer, as their area of interest is similar, while some do not overlap in the area of work.

The inclusion of students from the winning conceptual design in the three decision-making working groups (general design, managing and exhibition) ensures a coordinated development of the project, and that the final outcome does not deviate too much from the original concept.

The second phase of the course lasts for about 10 weeks. During this phase, the project is being developed and elaborated in details. The tests of the materials and structural calculations are conducted. At the end of the phase, each group is obliged to provide the results of their work in different forms: reports, design of a Web site and of promotional materials, various calculations, detailed shop drawings, a budget and the timetable of the production.

The third phase is the production and construction. In the first edition of the course (2018), the production phase was organised after the semester as additional workshops, which were opened for every student, but were not mandatory. In the second edition (2019), part of the work was done during the semester which takes about five short workshops, and part after the course. In the third edition (2020), the production phase had to be cancelled, as the whole education at the WUST was on-line due to the Covid-19 pandemic [9].

Each of the phases requires that students have different approaches and rearrange their habits and roles in group co-operation. Through this flexibility, they can work in different situations during the whole project by adopting various defined tasks (see Figure 2). In addition, every phase requires different skills. The student co-operation between the FA-WUST and FCE-WUST runs on two levels. First, there is a co-operation in small groups. This is realised in the first and second phase of the course, in which the conceptual design teams (2-5 people) and the working groups (3-6 people) from both disciplines co-operate on certain aspects of their projects. The second level concerns the co-operation between the working groups, which takes place in the second and third phase of the course.



a) b) c)

Figure 2: Development of the ProtoLAB: a) concept design model; b) shops drawing; and c) final structure.

COURSE EVALUATION

To evaluate the impact of the ProtoLAB course on the acquisition of new skills by students and mutual learning, three types of information sources were analysed: teachers' observations, students' written reflections on the course provided in their final reports and verbal feedback.

There were 66 students in total participating in three editions of the ProtoLAB, from which 47 provided their reflections in the reports (editions 1 and 3), and all of them by verbal communication. The reflections were students' answers to the given questions that concerned the acquisition of new skills (*What have you learned during the course*?), assignment issues (*What was the most difficult, easy and interesting*?) and the course's general pros and cons (*What was valuable? What should be changed? How those changes can be implemented?*). The verbal feedback was discussed at the end of each course during the closing meetings.

At the meetings, students were asked to freely share their opinion on what they had learned from each other, what new skills they had acquired, and how the co-operation between students from architecture and civil engineering had gone, as well as what had been the biggest difficulties in such co-operation. The closing meetings often changed into open discussion, where students shared their thoughts about the importance of interdisciplinary co-operation and educational benefits of the course. The teachers' observations were made per group of students (concept design group and working group) and discussed at the end of each phase, before formulating new design and production tasks. The opinions from the architect and structural engineers concerned the achievement of the didactic goals, group co-operation issues and further organisational steps. A qualitative analysis of these three sources of information was conducted and the results are provided below.

EVALUATION RESULTS

Up to date, there were three editions of the ProtoLAB course. While the first one (2018) was designated only for students of architecture, the second (2019) and third (2020) editions were intradisciplinary. At a general level, the students' top grades for the course, next to the high quality of the final project, the reports and the executed structure of the pavilion (excluding the 2020 edition) reveal the new skills acquired by students from both disciplines (see Table 1).

Table 1: Skills acquired by students from the Faculty of Architecture and the Faculty Civil Engineering.

<table>
<tr><td colspan="2">Skills acquired by architecture students</td></tr>
<tr><td>Technical knowledge and skills:
Understanding the influence of structural engineers on the whole design process.
Understanding the influence of structural engineering on the overall appearance of the building.
Understanding materials properties and ability to conduct laboratory structural tests.
Understanding structural statics and acquaintance with static calculation methods.</td><td>Learning different aspects of the structure stability and its load-bearing capacity influenced by the wind load, human factor, types of connection with the ground and overall structural system.
Preparing detailed shop drawings including the list of building elements.
Project management skills:
Paying attention to technical aspects of the project from the very beginning of the conceptual work.
Understanding project logistics, which include the size and weight of the elements, and which depend on market availability, costs, transportation, assembly, and the organisation of the building site.</td></tr>
<tr><td colspan="2">Skills acquired by civil engineering students</td></tr>
<tr><td>Technical knowledge and skills:
Understanding the meaning of aesthetics and perfection for the final effect.
Acquaintance with basic guidelines for architectural design and planning principles.
Understanding the influence of the design on the user experiences and functionality.
Understanding the consequences of structural solutions on the architectural form.
General soft skills:
Openness to creativity, freedom in decision making, inspiration for innovative and out-of-the-box thinking.</td><td>Recognition that profession of an architect is not an easy dream job.
Project management skills:
Understanding the project's idea, context, symbolism and metaphor of the architectural form and its meaning.
Acquaintance with project presentation and promotion methods, such as conceptual diagrams, visualisations, mock-ups and verbal communication.
Creating a project from the beginning, which includes the conceptual design phase.</td></tr>
<tr><td colspan="2">Skills acquired by students from both disciplines</td></tr>
<tr><td>Technical knowledge and skills:
Requesting permission to construct a pavilion in a public space.
Solving technical and production problems during project construction, updating drawings during the construction phase.
Ability to use construction tools.
Understanding the general (architectural) versus detailed (structural) approach.
Prototyping and construction of the project
General soft skills:
Team work, management, group communication.
Ability to work on a single, commonly selected project, regardless of its authorship.</td><td>Communicating between working groups and within them.
Understanding conflicts, compromises and other issues caused by diversity.
Understanding and openness to the other discipline.
Ability to establish proper contact with clients and sponsors.
Ability to receive and act on feedback.
Project management skills:
Preparing the budget and work schedule.
Preparing the full executive project.
Ability to perform the entrusted tasks according to the role in the team.
Learning the whole project path from concept to construction.</td></tr>
</table>

The positive aspects of the course most frequently mentioned by the students were: friendly atmosphere, inspiring nature of the assignment, interdisciplinary approach, realisation of one's own design, opportunity to meet new interesting people, in-depth discussion on the projects, common and democratic decision making, and the prototyping. There were also things that could be improved in next editions of the course, such as: give access to common software to all students, improve contacts with sponsors and clients, have a better grouping to recognise the complexity and amount of work in certain groups, appoint a leader in each working group, solve communication problems, assign inner- and cross-group responsibilities. The following comment on the course: *I am completing this course with one most important conclusion: the crucial thing is good communication between people who implement the project*, summarises the impact of this course on the students' approach to interdisciplinary work.

CONCLUSIONS

Interdisciplinary co-operation - between architects and structural engineers - is a crucial element of building design and construction. The ProtoLAB course has revealed that if interdisciplinary co-operation starts at an early stage of the project, its positive effects are numerous. For example, it brings innovative solutions, which reverberate in the beauty and functionality of the design, as well as in having lower costs, a smoother process and better organisation of work and construction.

Architects and engineers are rarely taught mutual collaboration during their studies. As they are separated at the university level, later, as professionals, architects and engineers have misconceptions about each other. Architects perceive structural engineers as insensitive and closed to innovation, *mentally rigid* professionals who carry out their calculations, logistics and construction tasks impassively and without identification with the project. On the other hand, structural engineers see architects as *light-minded* who, demand the impossible without paying attention to the fundamental laws of physics or to deadlines. Also, engineers believe that despite the work they have done, at the end, it is the architect who takes the credit for the project.

As demonstrated by the ProtoLAB course, interdisciplinary teaching - architecture and engineering - has a positive effect on overcoming these stereotypes. Students from both disciplines learn from each other, acquire mutual skills and abilities. The collaborative design process, from concept to construction, allows for a tightening of the co-operation between the disciplines, but also between people. While teamwork is a challenging part of the education, as it requires to combine different interests, to gather different opinions in order to make decisions, and to motivate all teams to deliver results, group co-operation provides for innovative and synergistically developed ideas.

The biggest challenge in implementing an interdisciplinary course is the communication between students of both disciplines, but also between working groups. Students are burdened with their habits, mental patterns, and the ability to use certain software, the way they express themselves verbally and by detailed sketches, which often causes misunderstanding [10]. An interdisciplinary course encourages and teaches them to break down their limitations and to open for the knowledge and skills transfer. Such training will allow them to have greater respect and mutual understanding, which can bring tangible benefits in their professional lives. Further steps to improve quality and to extend interdisciplinary co-operation may be the inclusion into the course of common design platforms, e.g. BIM software, and the integration of other disciplines, such as building services, electric engineering and industrial design. Another way is to create a track of architectural engineering, where interdisciplinary education of architects is based on engineering knowledge.

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