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Approaching technical issues in architectural education

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Summary

This paper discusses teaching of technical subjects in architecture, presenting two experimental activities, recently organized at Aalborg University - a two week long workshop and a one day long lecture. From the pedagogical point of view, the activities are strategically placed between conventional disciplinary courses and architectural design studios. On the one hand, this allows a better mix of theoretical lectures, exercises and design practice; on the other hand, narrow topic related to structural design may be deepened on the basis of a research-based approach to design.

Keywords: *pedagogy in architectural education; teaching/learning activities; construction workshop; teaching and research; structural reciprocity, conceptual design*.

1. Introduction

In our philosophy, teaching is an activity intended to guide, support and stimulate students in the development of an effective learning approach able to lead them towards a conceptual change in the way they see the world. Teaching is not simply a matter of acquisition and accumulation of information. It should be considered as a student-centred practice, strictly related to learning, aimed to lead students toward the development of: (a) acceptance of studying, (b) curiosity, (c) awareness, (d) deep content knowledge, (e) professionalism and precision, (f) method, (g) autonomy and independence, and (h) ethic thinking.

Focusing the attention on educational programmes in architecture, teaching/learning mainly takes place by means of disciplinary courses and more practical design studios. However, regarding teaching of technical subjects there is an intrinsic difficulty in applying theoretical concepts just by giving conventional lectures, as well as in highlighting the subjects' design potential from the architectural point of view. At the same time, it is also difficult to take advantage of such technical issues during wide-ranging design activities, and the final level of technical experimentation and innovation is generally lower than expected.

In this paper, we present two experimental teaching/learning activities, strategically placed between the two opposites of the disciplinary course and the design studio. They are: (a) the two week long workshop and (b) the one day long lecture, which may also be integrated in the workshop activity. Pedagogical issues as well as case studies and results are discussed in the paper.

2. A teaching framework

2.1 Kinds of knowledge and respective levels of understanding

Before designing our teaching activity, it is important to introduce and define which kind of knowledge and levels of understanding we want our students to achieve. However, 'knowledge' and 'understanding' are terms with a broad meaning and we need to structure them more first in order to have a valid support of our designing task.

According to Biggs and Collis [1], who defined the Structure of the Observed Learning Outcome (SOLO) taxonomy as a systematic way of describing how a student's performance grows in relation to the difficulty of different academic tasks, there are four plus one kinds of knowledge with respective levels of understanding. The first kind is prestructural, involving no knowledge, incompetence or the simple use of tautology to cover a lack of understanding. The following two are related to the category of declarative, or propositional, knowledge, which is quantitative:

- unistructural, in which the student's response only focuses on one relevant aspect. This level of understanding is expressed by verbs such as memorize, identify, recognize, find, label, recall, recite, etc;
- multistructural, in which the student's response focuses on more than one relevant aspects but they are still mainly treated independently. This level of understanding is expressed by verbs such as classify, list, discuss, illustrate, select, describe, outline, etc;

The last two kinds are related to functioning knowledge, which is qualitative. They are:

- relational, in which the learned aspects are integrated in a coherent whole and directly applied to real world situations. This level of understanding is expressed by verbs such as apply, use, analyse, organize, solve, explain, debate, construct, compare, etc;
- extended abstract, in which the integrated whole is finally conceptualized at a higher level of abstraction. This level of understanding is expressed by verbs such as reflect, compose, invent, theorize, hypothesize, generalize, create, etc.

The development of declarative knowledge comes earlier than functioning, and it is not required that all teaching/learning activities aim to reach the highest levels of understanding.

Another common taxonomy has been defined by Bloom and colleagues in 1956 [2] and successively revised by Anderson and Krathwohl in 2001 [3]. It differs from the SOLO taxonomy because it has not been derived from direct research on student learning, and its lack of hierarchy in the classification of levels of abstractions and cognitive domain. However, it may be used as reference to a longer list of verbs helpful for the definition of teaching activities.

2.2 Designing effective teaching

From the pedagogical point of view, teaching can be approached in several different ways. In this paper, the presented case studies have been developed within a Constructive Alignment (CA) framework, which is considered an effective outcome-based approach in Problem-Based Learning (PBL).

In this framework, teaching requires first the definition of a set of (a) Intended Learning Outcomes (ILOs), which are then used to construct and align (b) teaching/learning activities (TLAs) and (c) assessment tasks (ATs). ILOs, TLAs and ATs are the three elements forming the core of this teaching approach. The ILOs are defined using specific 'learning verbs' instead of the more generic term 'understanding', which express more precise levels of understanding that we want to achieve. Thus, TLAs and ATs are directly defined on the basis of the used 'learning verbs', and intrinsically reflect an 'alignment' with the ILOs. This follows Shuell's statement that "what the student does is actually more important in determining what is learned than what the teacher does" [4].

2.3 Teaching case studies based on the Constructive Alignment (CA) approach

Technical aspects such as structural, construction and material issues are an integral part of the development of an architectural project. In order to involve the students in considering and taking advantage of them in early conceptual design phases, it is important that they already master declarative knowledge on those subjects before designing. This may be generally acquired during a traditional disciplinary course, while its application is mainly stressed just in a design studio activity. These two teaching/learning activities may be conceptually seen as two opposites, in which the first emphasises the increase of declarative (quantitative) knowledge, and the second focuses on deepening the understanding by means of acquisition of functioning (qualitative) knowledge.

According to this and the pedagogical reflections illustrated in the previous Section, our aim is to develop and experiment with teaching which is strategically placed between courses and design studios. In architecture, the strict relation between the four kinds of declarative and functioning knowledge, and the respective levels of understanding, requires that such teaching/learning activities address them all as a whole as much as possible. At present, two main activities have been developed and experimented with in relation to teaching technical subjects in architecture. They are:

- a two week long workshop, which is conceived to run for seven working days distributed over two separated weeks (a case study is presented in Section 5);

- a one day long lecture, which alternates short lectures and design activities in a single working day, and can be also integrated in the two week long workshop (discussed in Section 4).

Both focus on a specific narrow structural or technical aspect of the architectural project, which is investigated with a research-based approach, starting from its background and state-of-the-art to the highlight of specific design issues, research directions and the development of design proposals and scale models and prototypes. Such activities are the result of previous experiments conducted by our teaching/research group in the field of shape-resistant structures and of studying the relationship between form and structure in architecture. Three workshops have been already run, the first in 2007 within the Master education at Politecnico di Torino concerning geodesic grid-shells [5], a second in 2008 at "Les grands ateliers" in Lyon regarding reciprocal structures, and the third in 2010 on timber spatial structures at Aalborg University. The results and some pedagogical reflections have been already presented at the First International Congress of ReteVitruvio in 2011, in Bari [6].

3. A construction workshop on the principle of structural reciprocity

The first two week long workshop was organized at Aalborg University during the fall semester 2011 of the Master of Science in "Architectural Design". It was conceived as an integral part of a 5 ECTS course module entitled "Engineering Architecture", aimed to present the students technical problems of interest for architectural design, focusing the attention on the creative potential of engineering topics of which they could take advantage during their design activities.

The long workshop is a research-based activity, focused on a specific narrow topic related to shape-resistant structures. In this case, we dealt with the principle of structural reciprocity, which we define as the use of load bearing elements to compose spatial configurations wherein the elements are mutually supported by one another [7]. The aim was to show the students how to approach these kinds of typologies in architectural design, in order to find new innovative spatial structures. In detail, we guided the students in:

- identifying a research and design topic (in this case, structural reciprocity);
- studying its background, relevance and current development in structural and architectural design (state-of-the-art in relation to basic reciprocal configurations, realized projects, design tools and strategies with both experimental and numerical approaches);
- highlighting its present limitations and design issues, in order to define potential developments for the generation of innovative concepts of structures and prototypes.

In this framework, we found the focus on the research/design activity of particular interest in the issue of three-dimensionality in structural reciprocity in order to force the design research of the students in a specific direction. In spite of reciprocal structures are intrinsically 3D, most of the existing configurations do not take advantage of this peculiarity. For this reason, we conceptually refer to:

- 1D reciprocal structures as configurations which are mainly developed in a linear way. The Leonardo's bridge may be classified as 1D structure since the use of fans composed by four elements is conceived to have a linear development from A to B;
- 2D reciprocal structures as configurations which are readable as surface-like geometries and allow a development along two main axes. Domes, polyhedra and several roof reciprocal structures may be included in this category;
- 3D reciprocal structures as configurations which are not belonging to the two previous categories. In this case, the conceptual reduction to reference surfaces or linear developments is not possible.

It should be underlined that this distinction is purely conceptual and aimed at forcing the design research of students in order to obtain specific configurations. Apart from this, we are not stating that reciprocal structures are not 3D in the physical space. Figure 1 shows examples of 1D, 2D and 3D reciprocal structures. Further details are provided in another paper by the authors related to the morphology of reciprocal structures [8].

Figure 1: Left, 1D reciprocal bridge inspired by the Leonardo's bridge; Middle, 2D reciprocal roof with fans composed by four elements; Right: 3D conceptual reciprocal structure by Popovic Larsen.

3.1 Defining the Intended Learning Outcomes (ILOs)

After the definition of the workshop topic and of which overall research/design issue to investigate, we defined the Intended Learning Outcomes (ILOs) according to the SOLO taxonomy. We expected that on successful completion of this workshop, the students would be able to:

- at a basic level, identify, classify and reconstruct simple and combined spatial configurations based on the principle of structural reciprocity (with the aid of physical models as design tool);
- furthermore, apply the principle of structural reciprocity to explore, study and design their own original configurations, according to the highlighted design issue (three-dimensionality);
- highlight and deal with a set of construction problems related to the construction of simple timber spatial structures, such as the seach for structural equilibrium, development of effective joints and assemblage of components, by realizing full scale prototypes;
- organize and coordinate their work in a team-based environment in order to efficiently build a full scale prototype in a short time;
- on a higher level, design architectural spaces according to the defined concepts of 3D reciprocal structures, taking advantage of and showing their peculiar structural and construction potential.

This list is organized in a hierarchical format, in which all the four kinds of knowledge and respective levels of understanding are involved. This allows us to naturally align the teaching/learning activities of the workshop, as well as the assessment criteria, to the expected outcomes. At the same time, the ILOs are a powerful tool for the students in order to self-assess themselves throughout the whole learning process.

3.2 Aligning TLAs and ATs with the ILOs

In order to reach the Intended Learning Outcomes, the students were called to:

- attend a one day long lecture with an exercise session on the principle of structural reciprocity, in order to identify, classify and reconstruct simple and combined reciprocal configurations;
- especially in the afternoon, focus on the issue of intrinsic three-dimensionality of reciprocal structures in order to explore, study and design their own new configurations (see Section 4);
- organize and coordinate their work in both individual and group sessions, in order to efficiently use the limited amount of time for the development of scale models and full prototypes (for further details see Section 5);
- highlight and deal with a set of construction problems related to timber spatial structures in order to develop their scale models and design/build full scale working reciprocal prototypes;
- reflect on the stressed design issue (three-dimensionality) by writing a paper in order to evaluate the workshop results, both internally and in relation with the state-of-the-art on the subject.

The final assessment has been also intrinsically aligned to the ILOs and the defined TLAs. A direct evaluation of the workshop results has been combined with a review of the final papers required of the students, in order to check their preparation in all the four levels of understanding.

4. Approaching the topic with a one day long lecture

4.1 Structure, organization and results

A one day long lecture was defined as the kick-starting activity of the workshop. The day was divided into four modules of two hours each, alternating two modules of frontal lecturing with two hands-on modules dedicated to individual tasks. In the morning session, the principle of structural reciprocity was introduced with a set of visual examples of different spatial configurations, as well as basic rules on how to construct them by means of scale models. Several reciprocal structures were presented with models, drawings and reference projects, focusing the attention in the morphological difference of assemblages as well as on the issues related to their conception and construction. At the same time, previous workshops and a historical recall about reciprocal structures were shown with the purpose of proposing a first design task, to be completed in the following two hours.

The students were called to identify differences in reciprocal structures and reconstruct some basic ones during the first hour. Thus, they should dedicate the second hour to compose them in more sophisticated configurations, still referring to existent projects if needed. Figure 2 illustrates some moments of this first practical sessions.

This task has been conceived with a dual objective. On the one hand, students become familiar with existing basic and more complex reciprocal configurations. On the other hand, they deal directly with problems related to the assemblage of elements accordingly to the principle of reciprocity, experimenting form-finding issues as well as a conceptual change due to the use of physical models as main design tool.

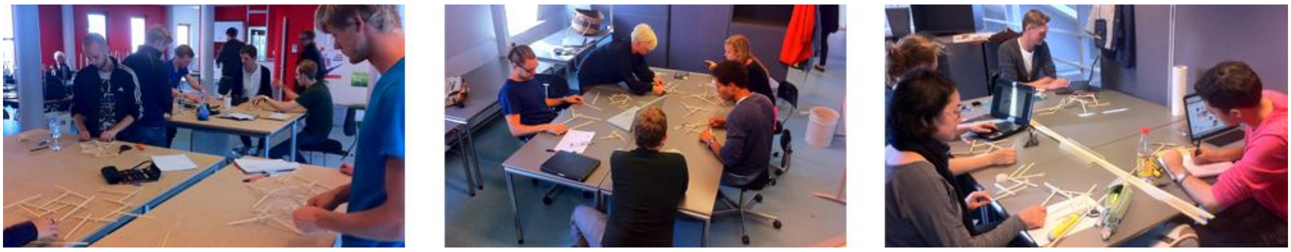

Figure 2: Development of basic reciprocal configurations during the first exercise session.

In the afternoon session, the frontal lecture started with highlighting the design issues emerged in the first assigned task. Representation problems as well as design tools and form-finding of reciprocal structures were discussed in a detailed way, also considering that we expected a higher level of awareness of the importance of such issues from the students already after the morning sessions.

Finally, the second design task was focused on a specific issue of the workshop, i.e. the search for full 3D reciprocal configurations which could not be conceptually developed in a linear way (1D) or simplified and read as surfaces (2D). The students were called to define a set of two-dimensional patterns, in order to 'break' them in three-dimensional configurations, as already made by Rinus Roelofs in some of his own artistic experiments [9]. Figure 3 shows the design task as presented to the students, while Figure 4 reports some of the 3D configurations developed during the two hour exercise.

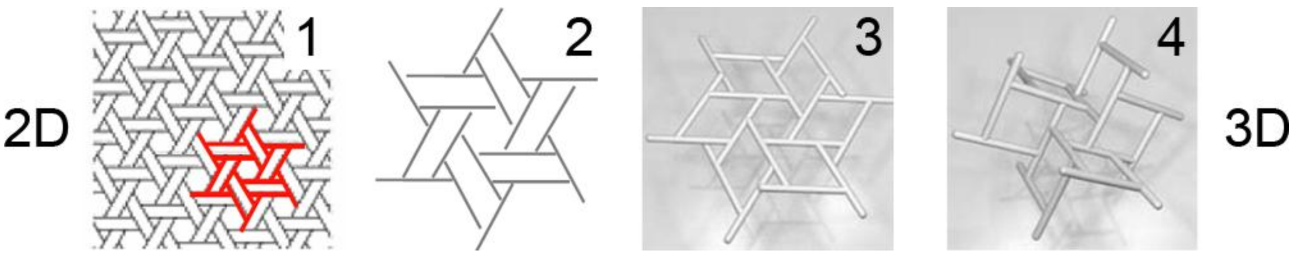

Figure 3: 2D patterns and respective 3D configurations by Roelofs.

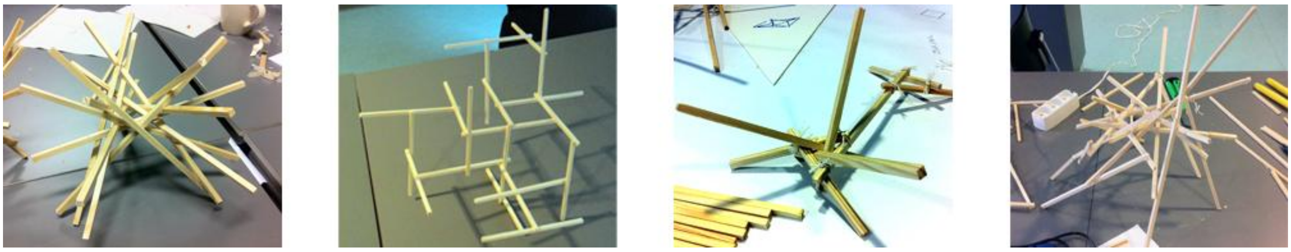

Figure 4: 2D patterns and respective 3D configurations by the students.

4.2 Pedagogical issues

The one day long lecture may be a very efficient way of teaching technical subjects in architecture. However, there are some pedagogical issues to take in account:

- this activity may be used to introduce shape-resistant structural typologies, as well as to present basic structural questions such as equilibrium to students at the bachelor level. The intuitive explanation of concepts, directly focused on their architectural design potential, may be an effective way to kick-start any kind of technical course or design studio. However, this activity cannot be considered as extensive enough to fully cover the necessary declarative knowledge the students have to develop on engineering issues. Depending on the educational level, an additional one day long lecture or more conventional lectures may be necessary to fulfil the course requirements and expectations;
- in this activity, time is a key issue. The amount of information to discuss, as well as the type and difficulty of the assigned exercises has to be carefully calibrated in advance, especially according to the level of students and their previous experiences. It could be a risk to experiment with this activity with a new class of students, without knowing about their background in advance;
- this activity requires a high degree of flexibility from the teacher. The afternoon session can recall some of the experiments made by the students during the morning session, and the teacher should guide them properly so as to get some minimum expected results. A good balance of preparation and adaptation from the teacher is necessary in order to succeed;
- co-teaching may be effectively applied within a one day long lecture, especially with large classes. Supervision of the exercise sessions is easier and the flexibility required from the teachers by this kind of activity may stimulate interesting discussions held by two different points of view. Furthermore, morning and afternoon lectures can be held by the two teachers, alternating their role as lecturer and opponent/critic.

5. Deepening with design and construction

5.1 Structure and organization

Following the initial one day long lecture, the workshop was run during seven working days distributed in two separated weeks – the first related to the design of three-dimensional reciprocal configurations with physical models, the second for some design refinements and the final construction in full scale of few prototypes.

The overall workshop has been based on the idea that the class is a large research group dealing with a specific design issue, i.e. the search for new fully three-dimensional spatial configurations of reciprocal structures (see Section 3 for further details). The students started to work individually or in small groups without any specific restrictions by the teachers. However, during supervision we encouraged the dialogue and discussion among other students dealing with similar design explorations.

At the end of the first working day, we asked the students to select one picture and a brief documentation of their temporary results, and to submit this to the teachers by e-mail. Thus, the following working day started with a brief collective discussion of the overall results, evaluating them according to the assigned task. This collection of material at the end of a working day, and the following common discussion as kick-start activity of the following workshop day, was repeated during the first week. This allowed both students and teachers to have a periodic check of workshop developments. Furthermore, it has been a fundamental aspect to guide the design research towards specific directions in order to finally converge on just seven qualified concepts to be refined and built in 1:1 scale.

The second week was mainly related to the construction, and three working days were estimated as proper time to also deal with possible unexpected difficulties related to the building site, materials and tools. This part of the workshop was mainly organized by the students, who had to deal with the coordination of large groups (10-13 students each) in order to build just seven representative prototypes of the workshop. Figure 5 shows the final prototypes realized by the students.

Figure 5: Five final 3D configurations realized by the students of the workshop.

5.2 Pedagogical issues

Several reasons show how this activity is worth to be further investigated and experimented with:

- the topics involved are narrow enough to allow both teachers and students to deepen the investigation of the subject from a theoretical and practical point of view. Generally, in architectural educations, the design activity is based on the development of complete projects, i.e. a sort of realistic simulation that the students will be called on to develop after the school, as architects. This could be problematic at an educational level due to the complexity of real projects and as such due to the difficulty to focus on specific design issues and related learning goals. On the contrary, the workshop deals with clear topics taken from research, and brings them inside architectural design by means of assigning 'design issues'. The acquired knowledge may be easily preserved, further developed and applied later in following design experiences;
- teaching and research can be effectively integrated in this activity. The workshop could be inspired from recent research issues of the teachers, and at the same time their future development may benefit from the conceptual and practical work of the workshop;
- the duration of the workshop is a key aspect. It should be long enough to guarantee a proper development of the design proposals, but at the same time it has to be dense and calibrated in order to fit between other conventional teaching activities of the semester;
- individual and group activities are completely merged in this kind of workshop, giving the students more responsibility on how and when to decide to work as a single designer or in a larger team. This is an important point especially in Problem-Based Learning educations as at Aalborg University;
- this activity is very time-consuming for the teachers, since daily activities have to be checked and evaluated at the end of the day in order to organize and effectively guide the students with the introduction of the following day activity. High flexibility in recalibrating exercises and expectations day by day is also needed to succeed;
- finally, some practical questions, such as funds, working spaces, weather conditions and tools may highly affect the success of the workshop.

6. Conclusions

Teaching technical subjects in architectural education means to focus on learning how to approach structural, material and construction issues so as to highlight their creative design potential, of which an architect may take advantage of for the development of new and innovative projects.

According to the SOLO taxonomy, conventional disciplinary courses and design studios are not flexible enough to deal with all the four kinds of knowledge and thereby achieve the four respective levels of understanding. Pure declarative knowledge should just be seen as a starting point for designing, especially in architecture. In this framework, two experimental teaching/learning activities have been presented as new ways to address all kinds of knowledge as a whole.

A two week long workshop on structural reciprocity and a related one day long lecture have been organized and run showing their potential as effective ways of teaching technical subjects in architectural education. Within these experiences (a) narrow topics may be dealt with a research-based approach, with a special focus on the design potential of structural, material and construction aspects for architectural design, (b) teaching and research may be highly integrated, (c) individual and group working methods are used and alternated, (d) co-teaching may be easily integrated to emphasize different points of views, stimulating critical thinking, and (e) relatively short activities may cover demanding topics with a continuous check of the achieved results.

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