INTUITION AND EXPERIMENTATION AS TEACHING TOOLS: PHYSICAL AND INTERACTIVE COMPUTATIONAL MODELS

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Abstract

Structural design and analysis is generally not the favourite subject among architecture students, who find it hard to assimilate abstract structural concepts expressed in complex formulae, whose translation to specific structural phenomena and application are not clear to them.

This paper presents a teaching innovation project that seeks to include intuition and experimentation in the learning of concepts related to the buildings' structural behaviour. Direct experimentation allows a better understanding and assimilation of concepts and increases motivation. The idea is to "take the laboratory to the classroom" through physical models that the students can build and test. These models are specially designed for the visual, intuitive, and clear explanation of one or several structural concepts.

The combination of these physical models with the development of interactive, computational structural models based on graphic statics allows the students to predict the behaviour of the proposed structure and immediately check the correction of their prediction with the physical model. The geometry-based approach to the teaching of the structures through graphic statics, together with the use of the parametric models and the experimentation with physical models result in an intuitive, interactive and easy-to-understand method for the teaching of structures. Furthermore, the experimental and visual character of these teaching activities makes them more appealing for architecture students and results in a higher motivation and participation in the classes, which, in turn, comes with higher academic performance and grades.

Keywords: structures, teaching, architecture, physical models, interactive, parametric models.

1 INTRODUCTION

Despite the obvious importance of the study of building structures within the curriculum of Architecture, this is a field that usually arouses little interest among the students. In many cases, courses about structural design and/or analysis are perceived by students as inconvenient and annoying obstacles on their way to earning the Architecture degree. This affects their performance and grades, decreases enrollment in elective courses on the field, and results in students who, passing the rest of the subjects, accumulate fails on those about structures. The difficulty of assimilating abstract and/or complex concepts, whose translation to concrete structural phenomena and whose application they do not see clearly, is a direct cause of the low motivation of the students.

The project presented in this paper is an on-going project supported by the Institute of Education Sciences ("Institut de Ciències de l'Educació", ICE) at UPC. The project tackles the problem of lack of motivation in the structures courses by including intuition and experimentation in the classroom as motivating teaching tools to improve academic performance. This is achieved by introducing the so-called experimental kits, physical models available for the students to explore structural design possibilities and for the teacher to explain structural concepts.

The use of physical models is a common practice in the teaching of architecture [1] [2]. Specifically, in the field of structures, many schools include the construction and testing of structural models by the students in their first years [3]. As an example, it is worth to mention the traditional, 3-m-span bridges made of timber and thread that groups of first-year students make at Vallès School of Architecture (ETSAV, UPC), where their testing is a well-known, expected and crowded event every semester (Figure 1). These are single-use models to materialize the students' design ideas and are very helpful for them to learn, among others, the process from the idea to the structural model and the link between structural behaviour and construction, material, shape…

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Figure 1. Testing of the structural models made by first year students at ETSAV (UPC).

The experimental kits proposed in this project are not designed and built by students, but brought to the classroom by the teaching faculty. They are designed and fabricated to teach specific structural concepts to be studied at a specific moment of the course of structures, following a similar idea as the teaching work presented by Prof. Lorenzo Jurina in [4].

The main objectives of the project are the following:

- Improvement of understanding of structural concepts.
- Increase of motivation in students.
- Improvement of academic performance.
- Increase of the number of students enrolling courses on structures.

2 METHODOLOGY

The methodology followed to carry out this project is summarized in the next steps:

1. Identification of the structural concepts to work on.
2. Study of the possible experimentation kits for the explanation of each structural concept.
3. Construction of the experimentation kits.
4. Introduction of the kits in the courses.
5. Monitoring and evaluation of results.

The structural concepts selected to be explained or explored with the experimental kits were those complying with the requirement of having the possibility to be featured with physical models that present the phenomenon clearly and visually. According to this, three kinds of experimental kits or physical models were envisaged:

- To support the explanation of concepts
- To explore possibilities in structural design
- To check structural behaviour predictions.

The final form of each model or kit was studied based on its clarity, ease of construction, the possibility of experimentation by students and the ability to explain different concepts with the same kit.

The finished kits were taken to the classes to explain the different structural concepts. Students were able to experiment with them and carry out structural behavior prediction exercises to be checked by testing the physical models.

The grades of the students together with the answers of an anonymous survey filled by them at the end of the course were used to evaluate the results of the project.

3 EXPERIMENTAL KITS

This chapter is devoted to the explanation of the experimental kits fabricated or acquired during the project (Figure 2).

Once the structural concepts that could be explained through experimentation had been identified, the possible kits were studied and, for each of them, the best way to build them based on cost, time spent and the quality of the final result was evaluated.

Figure 2. Some experimental kits of the project.

3.1 Kits to support the explanation of concepts

These kits are used by the teacher during his/her explanations.

3.1.1 Arches in 2D

This experimental kit is useful to explain the arches' structural behaviour. It has many different possibilities to explain different kind of arches with different boundary conditions, loading hypothesis, buttresses, etc. It has the advantage that the diversity of options can be very easily and quickly mounted (Figure 3).

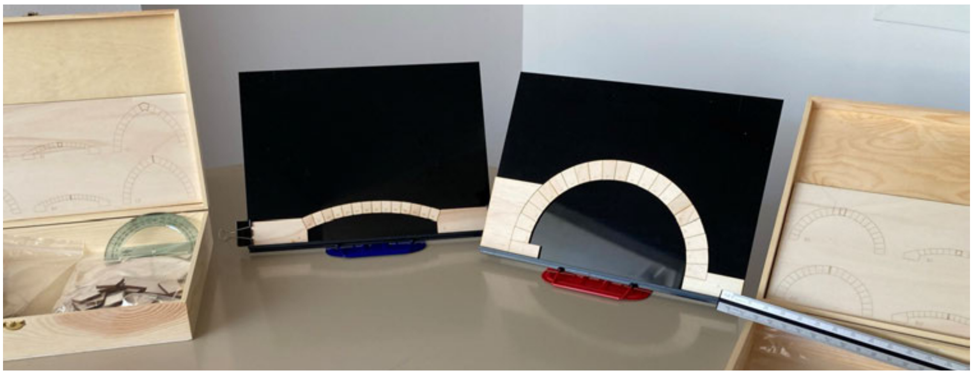

Figure 3. Kit of Arches in 2D.

3.1.2 MOLA Kits

"Mola is an interactive physical model that simulates the behavior of architectural structures. The model consists of a set of modular pieces, allowing countless combinations" [5] (Figure 4). These models are extremely versatile and easy to use, and are very helpful for the teaching of structural concepts such as stability, deformations, buckling and connections in frame structures. Furthermore, cable structures and trusses can also be explored.

The possibility to 3D print and build a similar kit was evaluated. However, the purchase of the MOLA kits was chosen as a better option considering, among others, cost, quality of the models, versatility and time required.

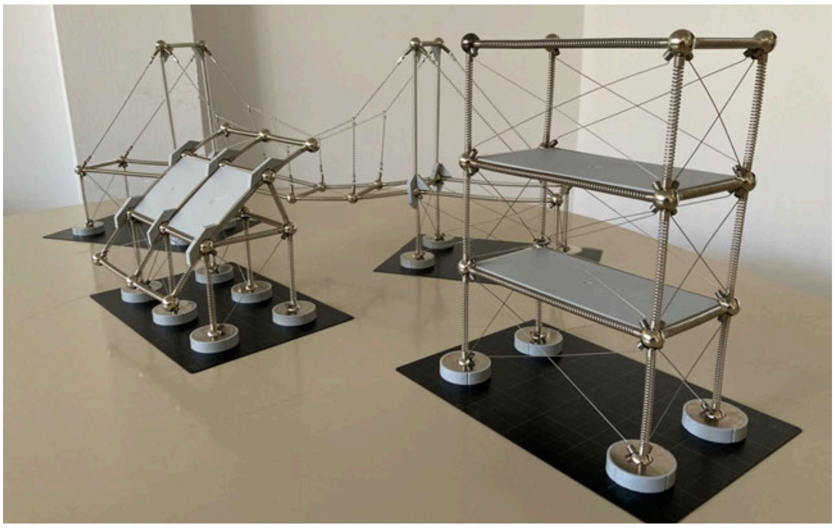

Figure 4. MOLA structural kits.

3.2 Kits to explore structural design

Although any of the previously-mentioned kits could be used to explore different structural designs, the experimental kits presented on this section focus on the form-finding of tension- or compression-only structures, i.e., the exploration of optimized shapes working only in tension or only in compression.

3.2.1 Chain hanging models

This kit (Figure 5) allows students to create funicular equilibrium solutions to investigate design possibilities with a structural constraint: chains work only in tension. Knowing that "As hangs the flexible line, so but inverted will stand the rigid arch", as Hooke formulated in 1675 [6], the students are able to design compression-only shells (Figure 6). The kit is provided with different complements to make pillars or walls, to cut and hold the chains, etc.

Figure 5. Experimental kit to explore chain hanging models.

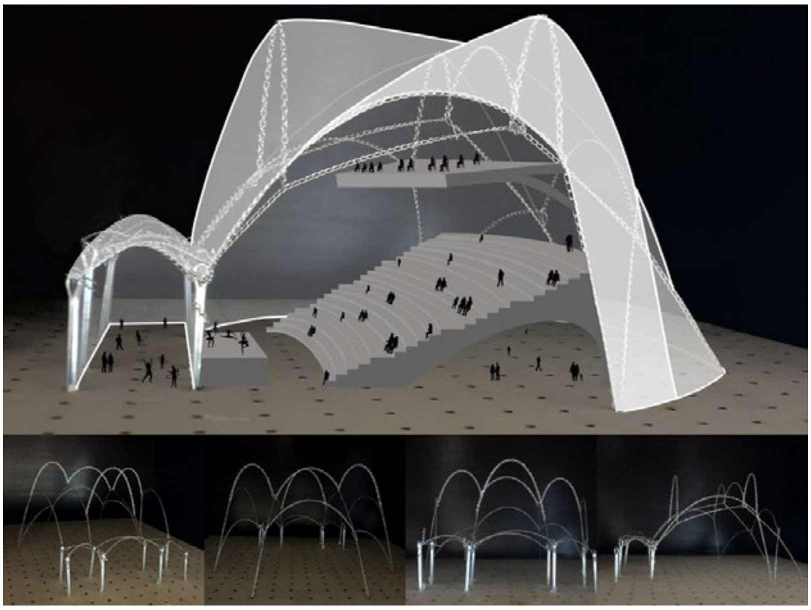

Figure 6. Hanging model and visualization by students
E. Arbona, C. Jaca, L. López and K. Narváez (ETSAV, UPC).

3.2.2 Gypsum hanging models

The same concept as in the previous experimental kit is used in this one. However, this time, fabric with gypsum is used as hanging material, resulting in a surface model (Figure 7), in contrast to the model made of a net of linear elements.

Figure 7. Kit to explore surface hanging models with gypsum.

3.3 Kits to check structural behaviour predictions

These kits are used in combination with exercises to predict the structural behaviour of specific types of structures. The predicted behaviour of the mentioned structures can be in qualitative or quantitative terms.

3.3.1 3D printed arches and domes

The students use this kit to check the correction of their calculations or their computational model. They can weigh and measure the voussoirs or structural elements to introduce the data in their calculations and predict, for example, the maximum displacement of the supports or the maximum load on the structure. Once they have a result, they can check its correctness by building, testing and monitoring the physical model.

These models were 3D printed with PLA (polylactic acid) material (Figure 8). The versatility of the 3D printer allows a quick adaptation of the kits to the specific doubts or requirements of the specific course, as the teacher can print eventual needed pieces to explain a concept in the next week's class.

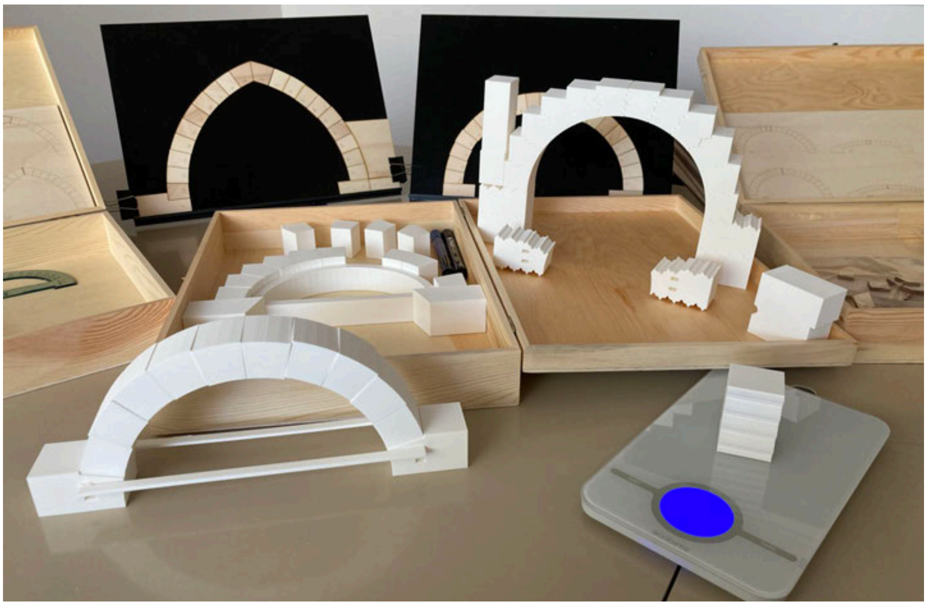

Figure 8. 3D printed experimental kits.

3.3.2 Arches in 2D

This kit, already presented in Subsection 3.1.1, may also serve as verification of qualitative results from exercises assigned to the students. For example, the configuration of the collapse mechanisms of different kinds of arches subjected to a diversity of loading cases could be checked (Figure 9).

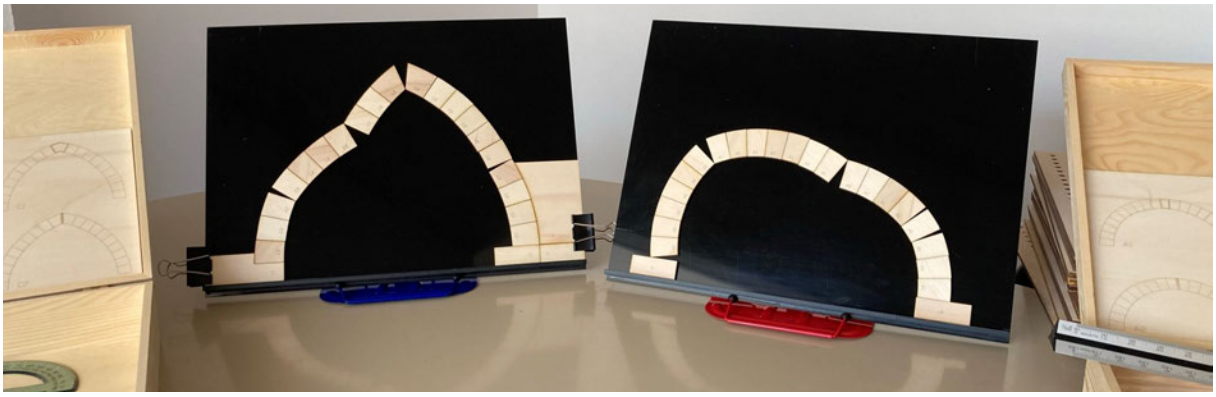

Figure 9. Experimental kit "Arches in 2D" showing collapsing mechanisms.

3.3.3 MOLA Kits

Just like in the previous case, this kit, already presented in Subsection 3.1.2, may also serve as verification of qualitative results such as, for example, the way a frame structure deforms.

4 THE KITS IN THE CLASSROOM

The experimental kits are introduced using the methodology of the "flipped classroom", in which the student performs with the teacher, in class, the high-level cognitive tasks of synthesis, assessment, solving complex problems with various solutions, etc., while the low-level ones (reading, listening, understanding, simple exercises of unique solution...) are carried out at home [7] [8]. This methodology requires the teaching material for the students to review at home to be extremely clear and self-explanatory. Audiovisual pills are very often used for this purpose. This way, students can adjust the time spent understanding the content according to their needs.

The class time is devoted, first, to a brief review of the most important or critical concepts with the help of the experimental kits, and afterwards, to resolving doubts, analyzing, creating, solving complex problems, and comparing, substantiating, contrasting, discriminating, and justifying chosen solutions, with the help of the kits as well. It is these tasks of high cognitive level in which the student requires more help, and those that traditional teaching usually leaves to be done outside the classroom. Many of these tasks are planned to be done in groups in class, thus encouraging collaborative work.

Thanks to this active methodology, 6 of the 7 principles of quality teaching set out by Chickering and Gamson (1987) [9] are guaranteed in class hours:

- Encouragement of contacts between students and faculty
- Development of reciprocity and cooperation among students
- Use of active learning techniques
- Provide prompt feedback
- Emphasis of time on task
- Respect for diverse talents and ways of learning

Considering this, and according to Chickering and Gamson, the teacher only needs to "communicate high expectations" to then achieve compliance with the 7 principles mentioned.

This on-going teaching project features an approach to the study of structural analysis and design based on geometry [10]. Taking as starting point the remarkable work done by Lee *et al*. (2021) [11] and Maia Avelino *et al.* (2021) [12], the authors currently explore the combination of the physical models with the development of interactive, computational structural models based on graphic statics, allowing the students to predict the behaviour of a range of structures and immediately check the correction of their predictions with the experimental kit, changing the position of the loads and some characteristics of the physical model, which will be specially designed to allow such modifications. The authors believe that the geometry-based approach to the teaching of the structures through graphic statics, together with the use of the parametric models and the experimentation with physical models will enhance the sought intuitive and easy-to-understand method for the teaching of structures.

In the subjects where the experimentation kits and the methodology have been introduced, these have been very positively valued by the students through anonymous surveys. The last survey carried out, with the project in the most advanced situation, showed that the students find the support teaching material adequate, more than 90% think that the content is presented clearly and they can follow the explanations with ease. Furthermore, 79% of the students would enroll in a second part of the subject.

5 CONCLUSIONS

Intuition and experimentation are teaching tools that can help in the explanation of structural concepts in a visual and attractive way, improving the students' motivation.

The introduction of experimental kits in courses about structures in the architecture curriculum at UPC was received very positively by the students. Anonymous surveys carried out at the end of the course showed that a majority of them found the kits helpful to understand structural concepts and they would enrol again in a similar course.

The present project will be continued and enlarged by studying possible further kits of experimentation and fabricating them.

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