CAD-CAM TOOLS IN STRUCTURES AND CONSTRUCTION SELF-LEARNING PROCESSES

**F. Magdalena-Layos, B. González-Rodrigo, G. García-López-de-la-Osa,
L.A. Zurita-Díaz, S. González-Rodrigo**

Universidad Politécnica de Madrid (SPAIN)

Abstract

This paper presents the continuation of previous experiences of self-learning through the realization of physical models by teams of students in a competitive environment. We added to the process the development of new skills as prior planning, the use of CAD tools and the manufacture of the models incorporating the CAD-CAM by means of a laser cutter.

Student teams are introduced in the use of procedures typical of their future professional activity, besides learning about structural behaviour. In order to build a structure, they must develop a project subjected to regulations (economic rules), economic restrictions (the amount of material they can use) and the limitations imposed by the laser cutter (technological restrictions)

The proposed challenge is developed during the course and concludes with the load test of the models and the subsequent analysis of the causes of the collapse, in an act in which students from the different participating schools gather together. The activity is completed with a conference given by a first level engineering firm that exposes real cases of construction of this type of structures.

Keywords: STEM experiences, learning by experience, structural models, multidisciplinary challenges.

1 INTRODUCTION

The difficulties of teaching and learning through abstract concepts in subjects that have a strong physical component, together with the emergence of new transversal skills (group work, leadership capacity, creativity, sustainability, etc.), sometimes difficult to implement and evaluate, highlight the need of new methodologies in the classroom. These methods should be based in experiential learning and involve the active participation of the students, in order to allow them to learn rehearsing.

The design, calculation and construction of structures require knowledge of very diverse fields: materials, mechanical properties, structural design, construction, etc. This multiplicity of points of view makes it difficult their integration into a single subject. On the other hand, learning them independently hinders their global understanding by the student. The possibility of gathering this multiplicity of points of view in a single experience, however limited, manages to confront the student with the complexity of the constructive fact from a holistic approach.

In addition, most of the teachers of subjects related to the structures and construction agree to appreciate the difficulty of understanding by the student of the physical concepts that underlay structural behaviour without making use of a strong mathematical apparatus that is oblivious to the baggage of these more generalist careers.

The verification of this difficulty has led to different methods proposed over time to undertake the study of structures in these general careers. We can cite different approaches to overcome this difficulty, as Salvadori [1], [2] that proposes examples of physical models. Antuña et al. [3], [4] through computerized virtual models, Khodadadi, [5] through an "Active learning approach", Alcorn [6] through "Experiential Learning", Emami [7] through "hands-on activities", and Vrontissi [8], Holmes & Mullen [9] or Estes & Baltimore [10] through the use of physical models at scale.

The approach chosen in the present case is the latter [10] organized in the form of a challenge, a competitive activity by teams. In addition, the use of physical scale models has a long tradition in engineering, see for example Vrontissi [11]. These models are especially useful in teaching construction, since it can hard to understand how something should be constructed without previously understanding how it works

2 METHODOLOGY

A first pilot test, with a reduced number of teams formed voluntarily, has been carried out by conducting a competition of structural models among students of the the Schools of Civil and Building Engineering of the UPM. This has allowed the exchange of experiences among students of subjects related to the construction and analysis of structures. The future goal is to extend this experience to a greater number of participants and perform a quantitative verification of its impact on the learning process.

2.1 Pedagogical goals

The present work aims at involving the student in an experience learning process based on the application of the acquired theoretical knowledge, not only in the specific subjects of structures, but also in the construction of a structural prototype fitting given rules and parameters. The model must be made with minimum fixed dimensions, and its parts must be obtained by laser cutting from a CAD design, using a maximum number of wood fibre boards, for all teams. Subsequently, on a given date the presented models are examined and subjected to load tests in a competition environment between teams of different subjects and schools. For those accepted models, the parameter that determines their effectiveness is the ratio between load supported and weight.

As can be deduced from the above, students must combine not only strictly structural knowledge, but others such as computer-aided design, or the concept of compliance with fixed norms. Therefore, in the future, it could be studied to extend the participation to work teams formed by students of different subjects.

2.2 Implementation

For this purpose, the activity entitled "TRIANGULATED STRUCTURE CHALLENGE ETSEM-ETSIC 2019" has been implemented according to the following bases:

- 1 The competition is open to all students of the Civil and Building Engineering UPM Schools. Teams can be up to three members. Each individual member may only be part of a team. Only one model is allowed per team.
- 2 Geometry and dimensions: The model to be developed will be a three-dimensional triangulated structure of 81cm free length between supports, with triangular cross section with edge below 20 cm and a width of at least 10 cm in its central zone. The geometry of each of the faces is free but the two sides will be formed by at least five triangles.
- 3 Students will decide all the characteristics not fixed in bases. For example, models with parallel or broken cords or even arcs with continuous cords can be developed. The layout is free, provided that its composition is maintained by means of linear elements forming hollow triangles, the use of surface elements being expressly prohibited.
- 4 The structure must be constructed from pieces obtained from cutting by laser cutter of a single 30x 50 cm DM board. For this purpose, each team must previously realize an exploded view in CAD of the pieces to be obtained. The elements obtained can be superimposed by gluing until reaching a maximum thickness of 10mm per bar. For tensile elements, low elastic braided yarn (with a capacity of around 10 kg) may be used with as many threads as desired. For the formation of the joint glue, staples or small auxiliary flat pieces of maximum dimensions 20x10x10 mm can be used.
- 5 The structure will be based on simple external supports (2, 3 or 4) without horizontal constraints and it will leave a free span (not axes, or including supports) of 81 cm.
- 6 The structure must include a load element in the centre of the bay from which the loads will be hung for the mandatory load tests.
- 7 The teams must register in advance, indicating name and surname, school, registration number and email address of each participant.

- 8 Before loading, all models must be weighed at the time, their value being annotated and exposed for later comparison. Together with the prototype, a video with a maximum duration of 2 minutes must be provided that includes the process of conception, construction and testing of the prototype, in which all team members must participate and appear.
- 9 The winner of the Challenge will be the model that, complying with all the requirements, achieves highest scores in following factors: 1) the best resistance-to-weight ratio, looking for a design suitable to the efforts resulting from the analysis; 2) the greatest structural difficulty and 3) the best design.

To increase the interest of the challenge, load tests will be carried out after a talk about structures of this type given by a leading engineering firm of the sector, in this case LANIK, which is also part of the evaluation jury.

2.3 Development of the activity

The best way to show the development of the proposed activity is through photos of the various phases of the activity of the winning team.

Figure 1

Figure 2

Figure 3

Figure 4

First, it is necessary to carry out a design as efficient as possible to respond to the structural requirements (Figure 1) and turn it into a project with measures to be executed (Figure 2). This project must be converted into a cutting template that respects the material limitations imposed (Figure 3) and it must be verified that the measurements obtained coincide with the original design (Figure 4)

Figure 5

Once it has been verified that the cutting template includes all the necessary parts (Figure 5), it is cut with the laser cutter (Figure 6). In this process the students experience manufacturing limitations such as laser intensity, step speed ...

Figure 6

Figure 7

Figure 8

Once the pieces have been cut, they are checked and reviewed if necessary and assembled (Figures 7 and 8). At this stage of the process, it is essential to understand how the unions should be performed so that they play their role correctly.

Figure 9

Figure 10

With all the participants together, it is checked that the model complies, it is weighed and the team proceeds to load it (Figures 9 and 10) until it is broken (Figures 11 and 12).

Figure 11

Figure 12

Figure 13

Figure 14

Finally, the team helped by the rest of the teams, the professors and the invited engineering dialogue and explain the causes of the collapse (Figure 13). The results are published (Figure 14) to be able to assess them as detailed below.

2.4 Evaluation of challenge results

Given the competitive nature of the activity, an "evaluation of the scale model challenge" was developed, which was announced to the participants before the load test, written in the following terms.

RATIO WEIGHT / LOAD (5p):

The general objective of the challenge is to assess the resistant capacity of the tested model. Therefore, the lower ratio between the weight of the model / sand load supported (kg) will be assessed very positively. This value will be taken in the instant before the total or partial breakage of the model. The deformations at this stage will not be taken into account, except in the case that several models did not reach breakage point.

MODEL DESIGN AND CREATIVITY IN THE SOLUTION (3p)

The models to be tested should be based on the conditions expressed in the statement, as well as respect the maximum and minimum measures required. It will be the jury that weights the models tested according to a design that suits the requirements.

GROUP WORK AND EXHIBITION (2p)

This is a group exercise, so it will be necessary to present evidence of collaboration in group work in a 2-minute video, included in section 10 of the work statement. Also, a brief oral presentation of the model will be necessary before loading, in which the 3 members of the group must participate.

3 RESULTS

Despite the warning included in the previous point, there were teams that did not meet the established conditions, so they were disqualified. The first learned lesson is the necessary respect to the limitations imposed. Even in these cases the students were satisfied with the work done.

In the other cases in which the limitations were respected, it was found that the students had correctly detected the two antagonistic structural behaviours (tension and compression) and had treated them appropriately.

4 DISCUSSION AND CONCLUSIONS

Previous experiences of students' elaboration of structural models at scale, which have subsequently undergone resistance tests in a competitive challenge among student teams, have proven to be helpful in the development of various aspects of learning. Its degree of utility is difficult to quantify given that these activities are included in the curriculum on a voluntary basis, but it has been a proven fact both by teachers and students that the achievement and, therefore, the average grade of students who have carried out these activities has been higher to that of those who have not done them. Whether this greater use may be due to a greater prior interest of the students or that it was the activity that triggered this greater interest is a fact that will have to be checked in the future, given the positive experience.

This type of activity is very well received by the students (Fig. 15). The simple fact of achieving this good attitude is already an achievement in matters that are difficult for them. However, despite the strong positive feedback and sensations of both students and professors, the small number of participants have limited a rigorous evaluation of the results obtained, especially the level of improvement in learning that these activities provide. Consequently, next course it will be repeated with more students and the participation of more schools.

Figure 15

ACKNOWLEDGEMENTS

We want to thank especially the engineers of the Lanik company, Antonio de Blas and Ibón Valle, for their dedication the knowledge transmitted and the Sika company for the material provided to prepare the models. Henry Daniel Meza Hilario, Jesús Barreno Broncal and Jorge Santiago Fernández provided the graphic documentation of the winning model.

REFERENCES

- [1] M. Salvadori, & R. Heller, *Estructuras para arquitectos*. Chicago, EE.UU. Ed. La isla.. 1969
- [2] M. Salvadori, *The art of construcción*. Chicago, EE.UU. Ed. La isla (1990)
- [3] J. Antuña. Creación de herramientas interactivas para la enseñanza de estructuras de Modelos virtuales de bóvedas nervadas de edificación: *Proyecto de innovación educativa IE1415-03015*, financiado por la Universidad Politécnica de Madrid. 2015.
- [4] F.Magdalena, J. Antuña, A. Aznar.& J.I. Hernando, "Using ArcoTSAM software as a learning tool in behavior of masonry structures". *Advances in Building Education*. doi:10.20868/abe.2017.2.3558
- [5] A. Khodadadi, Active learning approach in teaching structural concepts to architecture studens. *Proceedings of the International Association of Shells and Spatial Structures Annual Symposium*. Amsterdam, the Neatherlands. 2015.
- [6] C.G. Alcorn, Improving Student Knowledge through Experiential Learning. A Hands-On Statics Lab at Virginia Tech. *Project Report submitted to the faculty of The Virginia Polytechnic Institute and State University for partial fulfillment of the requirements of the degree of: Master of Science in Architecture, Construction Management Option*. 2003.

- [7] N. Emami, P. von Buelow, Teaching structures to architecture students through hands-on activities. *Canadian International Conference on Advances in Education, Teaching & Technology*. 2016
- [8] Vrontissi, M. The physical model in structural studies within architecture education: paradigms of an analytic rationale? *Proceedings of the International Association for Shell and Spatial Structures*. Amsterdam, the Neatherlands. 2015.
- [9] N. Holmes, & H. Mullen, Using Model Building in Structural Engineering to Enhance Understanding of Construction Principles and Methods *Irish Journal of Academic Practice*: Vol. 2: Iss. 1, Article 6. 1-21, 2013
- [10] A. Estes, & C. Baltimore, Using K'nex to Teach Large Scale Structures to Architects and Construction *American Society for Engineering Education*, Paper ID #9826, 2014
- [11] M. Vrontissi, The physical model in the structural studies of R obert Le Ricolais: "apparatus" or "hierogram" *3rd International Conference on Structures and Architecture, At Guimaraes, Portugal*, 2016