A Flipped Classroom experience: the lateral instability phenomenon

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Abstract

For a teacher, to inspire creativity and innovation is definitely a big challenge. One of the best ways that a teacher can use to get this result, it is an instructional strategy based on active learning such as the "Flipped Classroom". This paper describes a small Flipped Classroom experience developed at the school of Architecture of Politecnico di Milano and subsequently at the Université catholique de Louvain.

To develop this activity the students of architecture are invited to reflect on an important and difficult problem, both for the qualitative explanation of the phenomena and for the mathematical formulation: the lateral instability phenomenon. In general, stu-dents of architecture do not possess the knowledge for dealing with this phenomenon. This situation stimulates the reflection and the collaboration among students.

Keywords: Active Learning, Flipped Classroom, Education, Creativity.

1 Introduction

The world that we now live in has been radically changed by the progress of computer technology. Computer-aided drafting, analysis and design software have transformed the approach to structural design and computing [1, 2]. Since the very beginning of their studies, Architecture students are allowed to use computers as a tool for exploring the design space. On the other hand, the abuse of computer technology may seriously compromise the development of their cognitive abilities such as creativity, originality and problem solving.

Although a theoretical base is essential for understanding the method to be applied, a sterile study with few or no reference at all to real life will hardly teach students how to efficiently solve design problems in an original way. In order to avoid passive, mnemonic learning, students can be encouraged to engage in their own learning process integrating the traditional ex-cathedra teaching method with active educational techniques, based on practice experiences and creative approaches.

Within active engagement strategies, the Flipped Classroom model inverts the traditional lesson rules: the class is turned into a dynamic, interactive learning environment where the educator supports and mentors students as they apply concepts and engage creatively in the subject matter.

2 The experience

Graduate students from Architecture Faculty, at Politecnico di Milano (2015) and at Université catholique de Louvain (2016) were involved in a flipped classroom trial test [3, 4], with lateral-torsional buckling of beams as the main topic of study. Classical analysis of lateral instability is very complex and it requires differential calculus to be solved. However, most of the architecture students lack adequate prior mathematics knowledge for understanding the theory behind the phenomenon. By inverted teaching, students were challenged to investigate the instability phenomenon in a beam using an unconventional approach: a silicon pot mat, a handmade "machine" for testing material properties and their intuition and creativity.

The experience takes place from an 18x18cm square pot mat with a plate grill. When the mat is bended, the plates are distinctly affected by lateral instability For any change noticed, the students have to analyse and guess a qualitative explanation of the phenomenon observed.

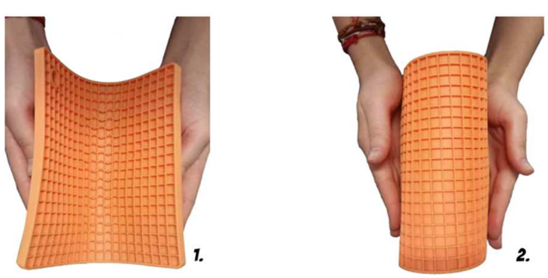

Figure 1. Bended pot mat.

An additional problem is the unknown value of the material Young modulus. The students have to design and assemble a rudimental testing machine to perform a simple tension test on the silicon pot mat and define the material's mechanical properties according to the experiment outcomes (Figure 2).

Students were able to directly experience the lateral instability phenomenon, observe the Poisson effect in action, and get acquainted with classical maths theories in structural engineering, without any support from the literature.

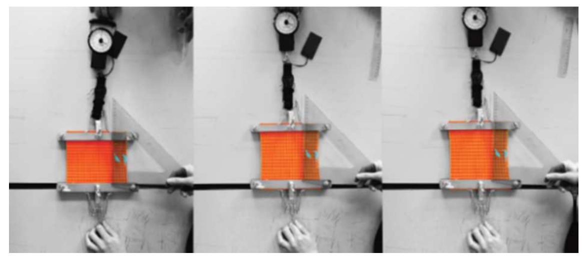

Figure 2. Tensile load tests.

This exercise represents a very stimulating activity for students, who become scientific researchers, and a powerful pedagogical tool for teachers, who turn into wise mentors, guiding their pupils to experiment unconventional approaches to acquire advanced knowledge and skills for investigating and solving complex engineering problems as the lateral-torsional buckling.

3 References

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To develop this activity the students of architecture are invited to reflect on an important and difficult problem, both for the qualitative explanation of the phenomena and for the mathematical formulation: the lateral instability phenomenon. In general, students of architecture do not possess the knowledge for dealing with this phenomenon. This situation stimulates the reflection and the collaboration among students.

Keywords: Active Learning, Flipped Classroom, Education, Creativity.

1 Introduction

The recent integration of new interdisciplinary aspects, such as social cost-benefit analysis of a structure, in structural design, has positively affected design and construction processes. [1, 2, 3, 4].

As often happens, architecture students are not interested in structural and science disciplines because they cannot see their practical application. Although a theoretical base is essential for understanding the method to be applied, a sterile study with few or no reference at all to real life will hardly teach students how to efficiently approach structural problems in an original way.

In order to avoid sterile, mnemonic learning, the traditional, passive, ex-cathedra teaching method has been integrated with active learning techniques, based on practice experiences and creative teaching techniques [5]. Students are encouraged to engage in the process of building and testing their own mental models from information that they are acquiring.

This paper describes a Flipped Classroom experience performed in 2015 at Politecnico di Milano, Italy and then in 2017 at Université catholique de Louvain, Belgium. Architecture students were challenged to investigate the instability phenomenon in a beam using an unconventional approach: a silicon pot mat, a handmade "machine" for testing material properties and their intuition and creativity.

Usually students find this topic difficult to be understood because they haven't the proper mathematics knowledge but Euler's theory for elastic buckling.

Thanks to this empirical approach and with the support of professors, students were able to directly observe, understand and then explain the instability phenomenon.

2 Active learning

Learning is a cognitive process of abstract concepts acquisition and elaboration of in-formation through the experience. People learn in different ways, and the way they learn may be affected by several factors (e.g. individual intellect level, social and intercultural stimuli, environment, etc.).

The idea of active-learning-based teaching models for cultivate students' cognitive abilities is not recent. Imitation learning (knowledge and behaviours come from imitating proposed models), heuristic methods (knowledge comes from educated guess, intuitive judgment and problem solving), and creative learning (knowledge comes from creative thinking and information processing) are some of the approaches commonly used. "Active learning" as concept dates back centuries, but it's been in the early 70s when it was first described by the English scholar R. Revans [6].

More recently, Bonwell [7] have used the concept of active learning to describe "instructional activities involving students in doing things and thinking about what they are doing." It implies that students are engaged in their own learning.

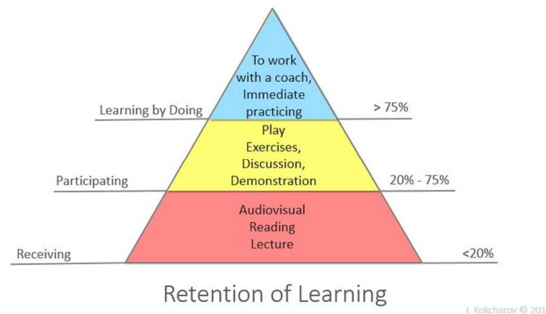

Figure 1, The Learning Pyramid, (Wikipedia).

Increase of students' motivation and participation in research, investigation, problem-solving and discussion activities are the major benefits for using active learning techniques. Several research studies demonstrate that this type of learning is more apt to stimulate higher cognitive processes and critical thinking.

Within active engagement strategies [8, 9] the Flipped Classroom model inverts the traditional and hierarchically rigid lecture in class - independent study at home - exam learning cycle: what is normally done in class is flipped with that which is normally done by the students out of class. Usually a Flipped Classroom consists of three steps [10]:

- STEP 1: Stimulation. The teacher stimulates students' interest, curiosity and thirst for knowledge. This is the first and most important step as effective learning comes from efficient cognitive and emotional engagement.
- STEP 2: Practice. The role of the teacher changes "from sage on the stage to guide on the side" (King, 1993). He/she becomes a tutor, mentoring the students according to each own need. During this phase students are challenged to apply cognitive strategies and investigation techniques typical of the discipline they are studying.
- STEP 3 : Data processing and results' discussion. The aim of this final phase is to explain and consolidate the learning gained. The teacher becomes the moderator of students guiding them in comparing and

discussing together final results and knowledge acquired during the active phase.

3 Lateral instability phenomenon: a practical experience

Classical analysis of lateral instability or lateral-torsional buckling of beams is very complex and it requires differential calculus to be solved. Because lateral-torsional buckling might occur in large structures (e.g. steel beam and steel truss), mastering this phenomenon and its structural consequences should be one of the basics of architecture design. However, most of the architecture students lack adequate prior mathematics knowledge for understanding the theory behind the phenomenon. Therefore lateral-torsional buckling is usually explained using simple examples (i.e. Euler theory for slender columns) and without referring to its implication in real structures.

Teaching advanced structural theories (e.g. lateral-torsional buckling) in architecture universities might be very challenging both for students and professors. However, using empirical methods may ease and enhance students' learning. A practical approach can definitely help students in understanding the mathematical theory behind the phenomenon they are studying.

Lebanese-American poet Kahlil Gibran once said "*I discovered the secret of the sea in meditation upon the dewdrop*". Inspired by Gibran's words, the investigation of the lateral-torsional buckling takes place from a simple and very familiar item, rather than from a large, complex structure: a 18x18cm square silicon pot mat (Figure 1) with a plate grill. When the mat is bended, the plates are distinctly affected by lateral instability (Figure 2).

Graduate students from Architecture-Building Architecture, Structural course integrated into Architectural Design Studio, at Politecnico di Milano (2015) and students from School of Architecture, Structural Design 2 course, at Université catholique de Louvain (2017) were involved in a flipped classroom trial test.

The paper will present the experience according to the three steps described in the previous paragraph.

Because step 2 is very complex, it has been divided it two parts: 2a and 2b.

The following chapters present students' significant observations and critical reviews on practical experience and outcomes. During the trial test students were divided into seven groups each having about eight members.

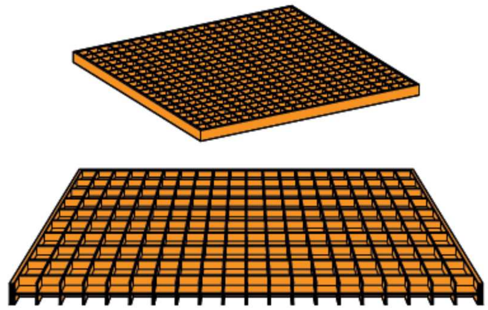

Figure 2. Pot mat model.

STEP 1 – Phenomenon observation, modelling, qualitative explanation.

First students have to analyse the silicon pot mat. The characteristic shape and material of the pot mat allow the students to directly experience the lateral instability phenomenon. (Fig. 2 on the left).

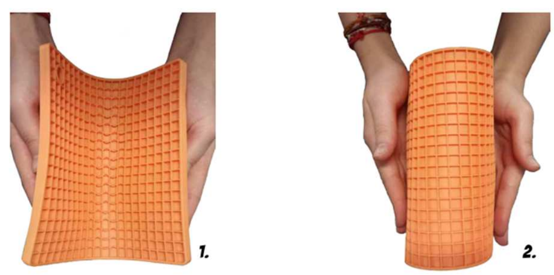

Figure 2. Bended pot mat. Left figure shows top fibres in compression and the instability phenomenon; right figure shows top fibres in tension.

Then students sketch what they have observed while manipulating the mat. For any change in tension and compression, the students have to analyse how the pot mat deforms itself and guess a qualitative explanation of the phenomenon observed.

First test: the pot mat is held in cylindrical bending condition and it is subject to incremental compression (Fig. 2). The following observations have been collected:

Observation 1. 7/7 teams have noticed that the instability phenomenon is limited to the central concave portion of the bent plate grill. Thanks to the knowledge of Bernulli-Navier beam theory and De Saint Venant bending of an isotropic beam problem, all the groups were able to correctly explain the phenomenon and identify the position of compress elements (concave area) and tense elements (convex area).

Observation 2. 7/7 teams have noticed that members subject to instability may randomly buckle sideways to the left or to the right. Slightly varying the bending, the behaviour may drastically change: the plates, which were buckling to the right, now turn to the left and vice versa. None of the groups (0/7) was able to justify the phenomenon.

Observation 3. 7/7 teams have noticed that the instability is more evident in the central area, while it significantly decreases in the plates close to the side (but still in the concave central portion of the mat). All the groups correctly hypothesised that the resistance to the phenomenon is related to the side-plate cross-sectional area (about 3 times thicker than the inner-plate one) and the higher moment of inertia.

Observation 4. 5/7 teams have noticed that a deformation affects also the cross members, but none of the groups (0/7) was able to justify it. Since it was a cylindrical bending problem, the students were expecting the plates perpendicular to the plane of bending remain undeformed.

3/7 teams have noticed that the deformation in the cross members is less evident than the one in the longitudinal plates.

Observation 5. 4/7 teams have noticed that both longitudinal and transversal elements are connected by a two-dimensional thin plate. 2/7 teams have noticed that this plate lays in the barycentre of the members (coincident with the neutral axis), therefore it should not affect the whole bending behaviour.

STEP 2a - Designing the testing machine to investigate material properties

In the second phase, by applying their structural mechanics knowledge, students have to demonstrate that the phenomenon observed in STEP 1 is a lateral-torsional buckling. A class discussion has been the opportunity to show the students how the lateral instability of the whole plate in the compression region (Fig. 3) can be roughly described as the Euler instability limited to the upper portion of the plate (i.e. 1/3 of the total height has been hypothesised to be affected by buckling). This approximation comes along with the assumption that the 1/3 upper area subject to instability is not connected to the lower part (Fig. 4 and 5).

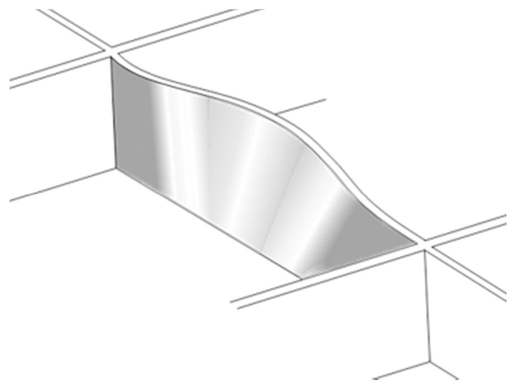

Figure 3. Bending of plate.

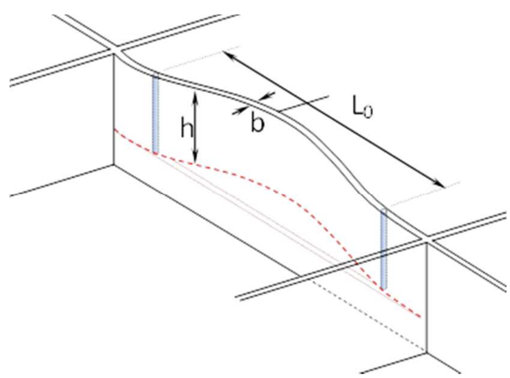

Figure 4. The assumption that the 1/3 upper area subject to instability is not connected to the lower part.

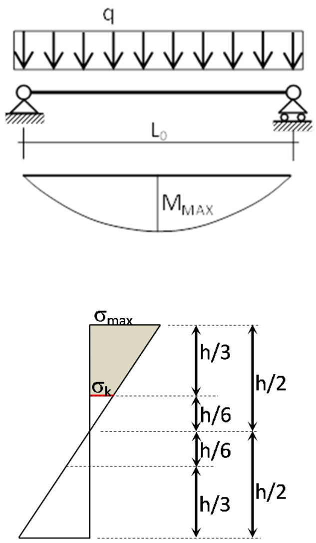

Figure 5. Bending moment and compression stress in the upper area.

The critical stress of the disconnected plate region can be evaluated using Euler's equation (known to architecture students by previous structural courses):

$$\sigma_{cr} = \frac{\pi^2 EI}{L_0^2} \quad (1)$$

The approximation is based on the assumption that if Euler critical stress of the detached portion is higher than the compressive stress (estimated by analysing the plate for bending), then there is no lateral-torsional buckling. If the previous validation is not satisfied, a lateral instability is likely to occur (necessary but not sufficient condition).

In order to perform this "non-validation", students consider I equal to the moment of inertia of one third of the section, and L0 (i.e. effective length) equal to the distance between two consecutive members subject to instability. This hypothesis is equal to assume a cylindrical joint as connection constraint (Fig. 4).

An additional problem is the unknown value E (i.e. material Young modulus). The students have to design and assemble a testing machine to perform a simple tension test on the silicon pot mat and define the material's mechanical properties according to the experiment outcomes. This time students were free to be creative; only few information about the possible development of the experiment were given to them.

Figure 6 shows an example of testing machine designed. Simple, ordinary items were used: a ruler for measuring the deformations, a hanger with butterfly screws as clamp and a luggage weighing scale as dynamometer for measuring the axial load during the test.

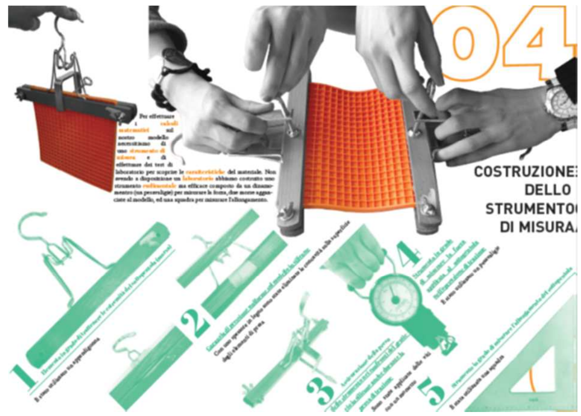

Figure 6. Designing the testing machine.

STEP 2b - Tensile load tests, statistical analysis and class discussion;

In the second part of the step 2, the students are performing the tension test (Fig. 7) for defining the Young modulus E. Each member of each group has to perform at least 10 tests with a different deformation each time (between 1 and 3 centimetres). In this way students can understand how important the statistical treatment of data is in defining the mechanical properties of materials.

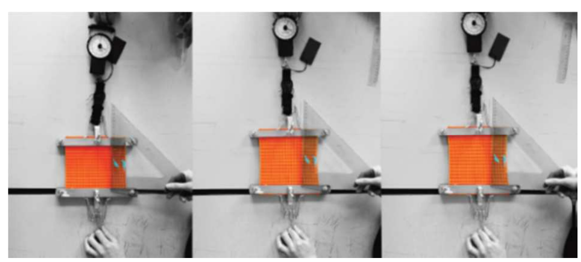

Figure 7. Tensile load tests.

During this phase the following observations were collected:

Observation 6. 2/7 teams have noticed that, during the tension tests, the thin bi-dimensional plate, which lays horizontally between plates in correspondence with the barycentre, affects the plate grill deformation due to transverse compression (Poisson effect).

Observation 7. 7/7 teams have noticed that, when pot mat is repeatedly tested, the Young modulus values found are different. All the groups explain the phenomenon with the measurer sensitivity (Fig. 8).

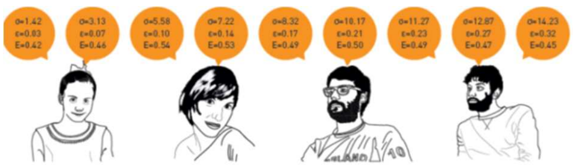

Figure 8. Measurement uncertainty.

Observation 8. 1/7 team has noticed that the more the tension is the more the tested element loses rigidity. The group wasn't able to explain the mechanical behaviour.

Observation 9. 2/7 teams have noticed that the plate grill is subject to a local deformation close to the clamps due to a large vertical compression. Both the groups thought this condition doesn't influence the efficacy of the tension test, but they weren't able to explain the phenomenon.

STEP 3 - Calculation and verification of the phenomenon using simplified methods.

Basing on the data collected, the material properties (Young modulus) have been statistically analysed for characterizing the material. The students have been actively engaged in bar graphs analysis and Young modulus estimation (Fig. 9).

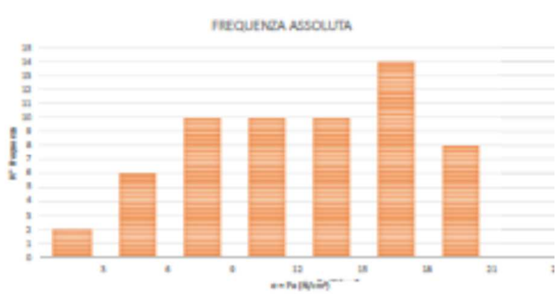

Figure 9. Measurements bar graph and Relative Cumulative Frequency graph.

This phase was crucial for its pedagogic value because the students were able to learn notions that usually are not explained during the course.

Based on the measurements, the following characteristic value of Young modulus has been estimated 0.2405 N/mm^2.

l = side length of the pot mat equal to 180 mm

Pot mat weight

$$P = 0.10[Kg] \cdot 9.91 \left[\frac{m}{s^2}\right] = 0.981[N] \quad (2)$$

Distributed load

$$q = \frac{P}{l} = \frac{0.981[N]}{180[mm]} = 0.00545 \left[\frac{N}{mm}\right] \quad (3)$$

Maximum bending moment at the centre of the whole pot mat:

$$M_{max} = \frac{ql^2}{8} = \frac{0.00545\left[\frac{N}{mm}\right]\cdot(180[mm])^2}{8} = 22.0725[Nmm] \quad (4)$$

n = number of plates on one side.

Mean bending moment on one plate:

$$\bar{M} = \frac{M_{max}}{n} = \frac{22.0725[Nmm]}{21} = 1.051[Nmm] \quad (5)$$

Then, considering the pot mat weight and geometry, the maximum bending stress of the structure has been evaluated to 0.032 N/mm^2.

Maximum stress evaluation

$$\sigma_{max} = \frac{\bar{M}}{W} = \frac{\bar{M}}{\frac{bh^2}{6}} = \frac{1.051[Nmm]}{\frac{1[mm]\cdot(8[mm])^2}{6}} = 0.098 \left[\frac{N}{mm^2}\right] \quad (6)$$

Stress on k-fiber at $h/6$ from barycenter

$$\frac{\sigma_{max}}{\frac{h}{2}} = \frac{\sigma_k}{\frac{h}{6}} \qquad \sigma_k = \frac{0.098[N/mm^2]}{3} = 0.032 \left[\frac{N}{mm^2}\right] \quad (7)$$

Assuming a height of section equal to a third of the whole height of the plate, the critic stress characterising the structure is equal to 0.002611 N/mm^2, about 38 times less than the real bending stress. This is the reason why the lateral-torsional buckling occurs.

$$I = \frac{b^3 \cdot \frac{h}{3}}{12} = \frac{1[mm^3]\cdot 2.666[mm]}{12} = 0.221[mm^4] \quad (8)$$

$$\sigma_{cr} = \frac{\pi^2 \cdot EI}{L_0^2} = \frac{\pi^2 \cdot 0.2405[\frac{N}{mm}^2]\cdot 0.221[mm^2]}{(8[mm])^2} = 0.00261[N] \quad (9)$$

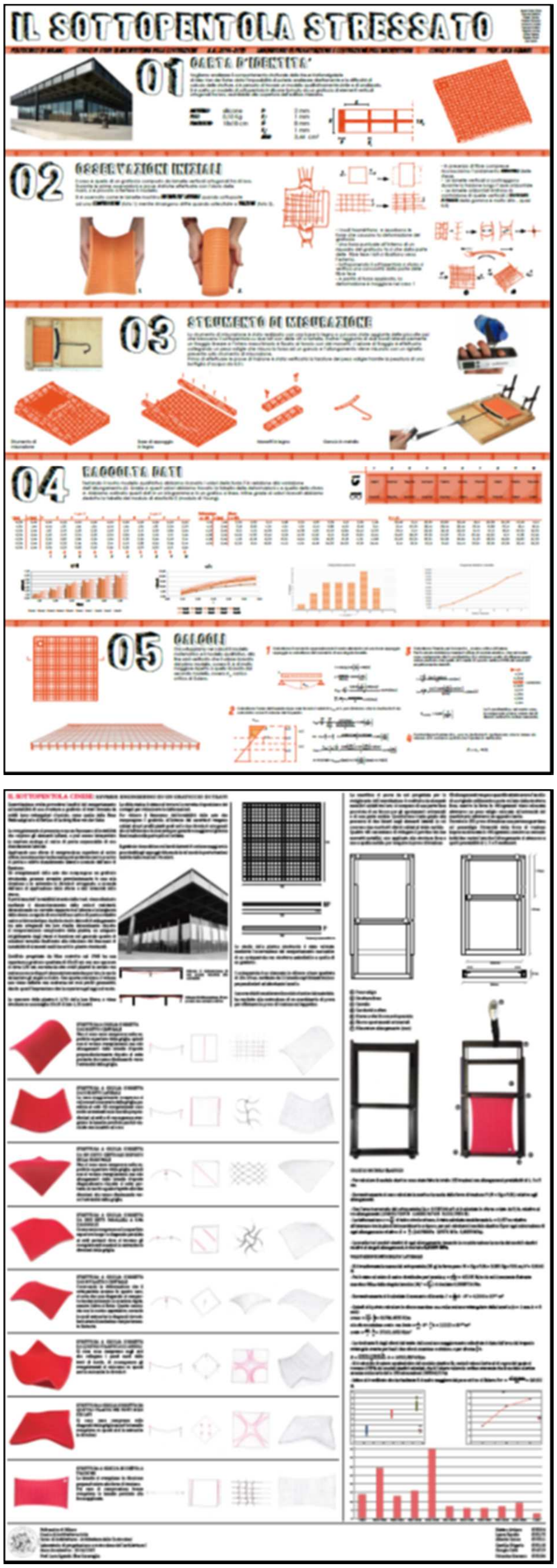

Figure 10. Synthesis drawings of the experience.

Basing on the previous observations, each team has developed some expedient in order to solve the lateral instability problem. Observation 10 summarises them.

Observation 10. 6/7 teams have suggested increasing the elements' cross-section. According to Observation 3, if all the members had the same section of the side ones, the lateral buckling wouldn't occur.

4/7 teams disagree with evenly increasing the cross section because it would be expensive and not effective to solve the problem (increasing the section of the tense area doesn't prevent the compress area from buckling). Teams have suggested adding a wing to the compression plates, turning the plate section from rectangular to T-shape.

1/7 team have suggested using the side, thicker beams as bracing for the inner, thinner beams. Additional transversal elements connecting the compression members to the side beams might avoid the lateral instability phenomenon.

Finally students have to be creative and summarise the whole experience in A1 format graphic work (Fig. 8).

4 Conclusions

The need for stimulating high cognitive processes, critical thinking, and creativity, and teaching how to approach complex engineering problems to architecture students were the reasons behind the decision to integrate the traditional teaching method with an active learning experience. Amongst all the active learning techniques, the Flipped Classroom is a fascinating experience, which engages and motivates students to study unconventional, challenging themes for a traditional course. Particularly during the exercise described in this paper, the students were able to integrate the usual curriculum with problems related to setting up a real test experience, statistical analysis, evaluation of mean and characteristic values of a distribution, and approximated theory for lateral instability test.

Furthermore the authors are persuaded of the high pedagogical value of this experience to enhance the critical thinking, foster a good teamwork and provide a scientific methodological approach to complex problems without any support from the literature. Such experiences, integrated with curricular theoretical knowledge, will positively influence students' education and their ability to deal with modern design challenges.

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