

Active learning for the promotion of students' creativity and critical thinking: a (practical) experience in structural courses for Architecture

Abstract

Recently it has become increasingly common amongst universities to incorporate Active Learning strategies into lesson plans to involve, stimulate and motivate students in developing creativity and critical thinking.

This paper describes an active learning experience of structural engineering addressed to students of Architecture and performed at Politecnico di Milano, Italy and Université catholique de Louvain, Belgium. Architecture students were asked to investigate the lateral instability of beams, in qualitative and quantitative terms, using a silicon pot mat.

The complexity of the problem and the unconventional approach adopted allowed the students to actively engage in a research-like experience, able to stimulate creativity and critical thinking.

1. Introduction

Learning involves a cognitive process of acquiring knowledge and information through experiences. The methods people use to learn are different and in general they are influenced by factors such as aptitude, prerequisite knowledge, social and intercultural stimuli, environment, etc. The teaching strategies for university students are commonly divided into passive and active. Most of civil engineering classes are based on passive learning with ex-cathedra seminars, PowerPoint presentations, white/chalkboard lectures. It is a verbal, one-way lecturing, where students passively listen and take

notes. The oral transmission of notions is integrated with practice exercises in the form of problems to be solved applying the knowledge gained (e.g. foundation design, wall stability analysis, etc.).

The same usually happens within schools of Architecture when civil engineering disciplines, which have an important role within the students' curriculum, are taught (Asefi & Imani 2018). However, due to the difference in aptitude and interest between engineering and architecture students, the former are more likely to be motivated and benefit from passive learning of technical knowledge critically important for their future profession. On the other hand, structural disciplines have the reputation of being difficult to learn and restrictive of design creativity (i.e. the most stimulating activity) amongst architecture students.

Active learning as a concept dates back centuries, but it was in the early 70s when it was first described by English scholar R.W. Revans (Revans, 1971). More recently, at the end of the 90s, Bonwell defined active teaching as a pedagogical strategy to engage students in their own learning (Bonwell, 1996; Andelka and Rahaela, 2014; Freeman et al., 2014).

Nowadays, several universities have implemented active methods in their didactics, challenging students with activities and tasks that are common to different disciplines and educational levels (Edwards, 2017). Walters et al. (2017) emphasize the importance of simulations and practical training in medical education and highlight the beneficial effects of active techniques on learner autonomy. Similar conclusions were drawn by Musikhin (Musikhin, 2014) in geospatial sciences. Moreover, Musikhin recognises that active learning strategies require substantial investments of time and energy to prepare lessons' activities.

If we examine pedagogic philosophy in schools of Architecture and schools of Engineering in a general way, we can state that the two philosophies have, on the whole, been developed with different approaches.

In the schools of Architecture, the main pedagogic activity is carried out in the Design Studio (Salama 2017). In these courses, which are based on active type of learning style, the student tries to apply the theories which he or she has learned to solve real problems. The teacher, on these courses, acts as a guide, helping the student to produce a high quality project, via a series of feedbacks given from time to time on the work carried out. This teaching model is already, to a degree, geared towards stimulating the student's creativity. Meanwhile, in the schools of Engineering, the dominant teaching model, as stated by Sell (2014), is the deductive one or the passive learning style, where the teacher is in control of the transmission of knowledge. However, this model is not sufficient for attaining in depth knowledge of subjects and for developing critical thinking. In this regard, Kersten (2018) highlights the importance of the active teaching style in the learning process of engineering subjects. In fact, if a passive teaching style is adequate in traditional engineering which only has to develop existing technology in order to resolve problems, discovering and inventing new solutions requires a different way of thinking and also, therefore, a different method of teaching (Kersten, 2018). Innovative pedagogy, introducing methods which stimulate the creativity of students, is an important topic. As is highlighted by Zernike (2009), when students' creativity is stimulated during their years of study, it can lead to greater work opportunities for them after they graduate.

In 2010, the International Journal of Architectural Research published an important Special Issue on the academic pedagogy of the schools of Architecture (Salama and Crosbie, Editors 2010). This volume gathered together 32 research articles with the

aim of creating a state of the art of teaching methods and introducing innovative methods into the various different disciplines which contribute towards the training of an architect. There is a helpful summary of the publications in the book's editorial to which reference should be made for further details. We, here, would like to mention the work of Hadjiyanni and Zollinger (2010) which, in order to increase the interest of students in studying the history of architecture, introduces a series of games and challenges alongside traditional pedagogy; the work of Mostafa & Mostafa (2010) which demonstrates how to develop spatial thinking skills in young architects by using an active teaching style; and the work of Desai (2010) which emphasises the importance of practical activities in the schools of Architecture.

Different authors have also looked at the problem of improving the didactic approach, above all to stimulate the creativity of students, in structural engineering subjects. On this topic, Banerjee and De Graaff (1996) emphasise the importance of an educational methodology based on a problem-based learning (PBL) approach for technical subjects (such as structural engineering). Little and Cardenas (2001) also suggest using a didactic approach based on Design Studios for schools of Engineering, whilst McCrum (2016) confronts students on his structural engineering course with interdisciplinary problems set out by students from a school of Architecture. In particular, McCrum shows how the act of looking for solutions to interdisciplinary problems can stimulate the ability to find creative solutions.

For these reasons, the authors decided to include some small active teaching experiences within a structural engineering course offered at a school of Architecture which was based on a passive teaching method, in order to stimulate the creativity and critical thinking of the students in relation to civil engineering subjects. For a better

understanding of the context in which the experience has been developed, in the next paragraph, one of the two courses taught by the authors will be analysed.

2. Analysis of the course in which the activity has been included

The active teaching experience described in this article was offered for the first time within a “Structural Design” course in the school of Architecture at Politecnico di Milano (in the year 2013) and was later incorporated into a course of “Structural Design 2” at the school of Architecture of Université catholique de Louvain (in the year 2016). Although the courses are in two different universities, they are similar in respect of teaching material (design of buildings in reinforced concrete and in steel) and level of teaching (first year of Masters of Science Course). The course at Politecnico di Milano is, however, a teaching module within a multidisciplinary architectural design studio, whilst the course at Université catholique de Louvain is an independent course. For a better understanding of the position of the active teaching method within these courses set out in this paper, the teaching material, objectives and organisation of the course provided by one of the authors at Université catholique de Louvain will be analysed briefly.

2.1 Teaching material

The Structural Design 2 course covers the design of buildings, both in reinforced concrete (whether in situ or prefabricated), and in steel. Within the course, students must be provided with the fundamentals for dimensioning these types of building, so that in parallel courses of architectural design students known how to think in architectural terms, checking the feasibility of the structures designed. Based on theory already absorbed by the students in previous years (isostatic buildings solution,

evaluation of the diagrams of internal actions, basic knowledge of materials and technologies), lecturers introduce calculation and verification methods for the structural elements (beams, pillars, walls and foundations) leading students to a multidisciplinary knowledge of the problem of the architectural project.

2.2 Objectives

Being the last Structural Engineering course, the « learning outcomes » that the students have to achieve during the Buildings Design 2 course are fairly high. However, they are in line with the capability that an architecture student should possess by the end of his/her studies. They include the ability to:

- 1) formulate and criticise a building's mechanical functioning;
- 2) assess the specific problems inherent to the design and make reasonable, coherent and rational choices;
- 3) assess the technical and construction principles of buildings of large scale;
- 4) analyse and understand technical documents;
- 5) discuss in a professional manner with the engineers, expressing rigorous structural observations;
- 6) determinedly pursue the implementation of his/her own ideas and the achievements of his/her own objectives.

When the action verbs in the learning outcomes (formulate, criticise, assess, make, understand, express, pursue) are examined in the light of Bloom's taxonomy which is often used to construct study programs (Larkin and Burton 2008, Birlik 2015), it suggests that the course should be structured in such a way as to pursue the most prominent points. In particular, taking as a reference the revised Bloom's Taxonomy

put forward by Anderson and Krathwohl (2001), as well as providing new concepts on the design of buildings, the course should lead students to be able to assess (“present and defend opinions by making judgments about information, validity of ideas, or quality of work based on a set of criteria”) and to create (“compile information together in a different way by combining elements in a new pattern or proposing alternative solutions”) new ideas (Anderson and Krathwohl 2001).

2.3 Course organisation

The teaching materials and objectives expressed in previous sections have suggested the adoption of a mixed type of teaching strategy in which the classical frontal lesson (where new concepts of dimensioning and verification of buildings are illustrated) is alternated with an active teaching exercise where students can formulate new theories, monitor and criticise structural behaviour, express their own ideas and pursue research which leads them to both qualitative and quantitative results. The task of introducing new concepts and of developing learning outcomes 2, 3 and 4, shown in the previous section, is given in the frontal lesson. The task of developing learning outcomes 1, 5 and 6, on the other hand, is assigned to the active teaching exercise.

The course, which is composed of 13 lessons, each lasting 3 hours, has therefore been organised according to the diagram of Figure 1. The frontal lessons, which are based on the classic concept of passive teaching, are for introducing new concepts, showing mathematical demonstrations useful for the comprehension of formulae, and for showing real applications on some works of contemporary architecture. The hour of exercise, which always follows the two hours of frontal lesson, is organised so as to allow students to apply immediately what has been illustrated during the previous two hours.

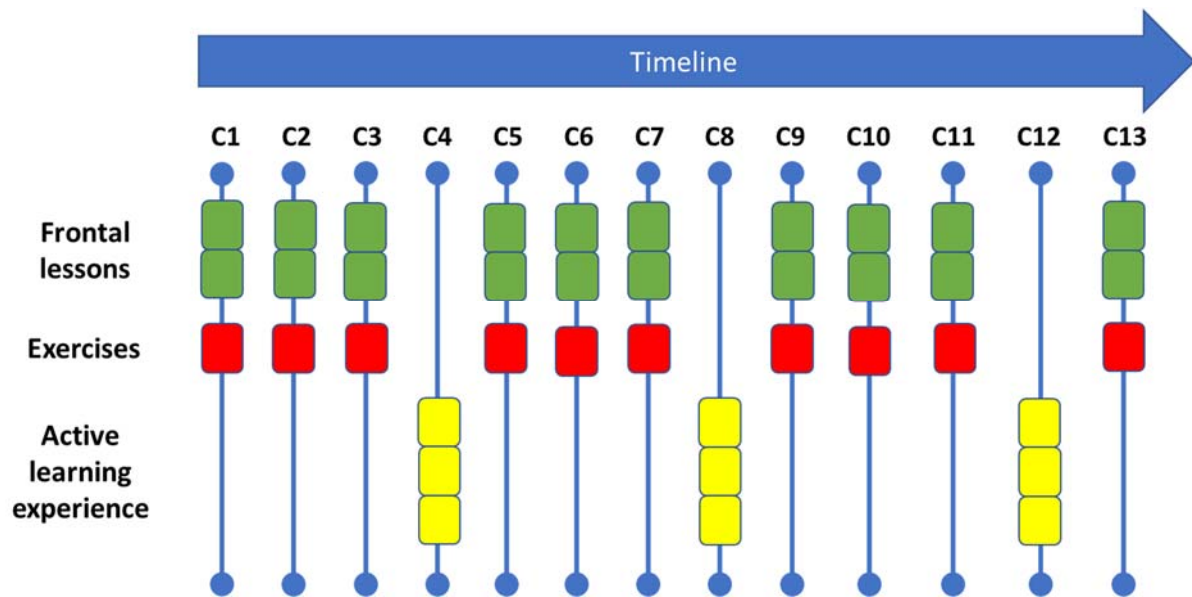


Figure 1. Organisation of the “Structural Design 2” course (Université catholique de Louvain, Tournai campus).

During this hour, the students are invited to apply the theoretical concepts explained by the professor to a series of contemporary architectural buildings, in order to analyse the particular problems of the structural design. For example, in lesson C2 (checks on the bending elements in reinforced concrete), the students must measure up and verify a floor of the Tama Art University Library designed by Toyo Ito, whilst in lesson C11 (dimensioning of retaining walls in reinforced concrete), students have to verify a retaining wall in the Carlton and Margaret Wall House of Frank Lloyd Wright. These real applications also allow the professor to introduce architectural aspects and to show students how the building and composition of the spaces are closely linked. Moreover, the exercises are structured so that they are started in class, in the available time, but are finished autonomously during the days after the lesson. Students’ work is corrected during the lesson following the exercise.

The active teaching method, which is the object of this paper, is used in three of the lessons - C4, C8 and C12 (Fig. 1). The aim is to increase the creativity and critical sense of the students in regard to the mechanics of the buildings. These activities will be set out in more detail in the following paragraphs.

2.4 Assessment of Students

Students are assessed on the basis of a written paper, where they must demonstrate that they know how to apply the new concepts learned during the course, and on the assessment of a report on the active teaching experience. This report is requested in the form of a table of A1 format in which groups of students must summarise the entire activity which has been carried out. For the evaluation of the two tests, assessment rubrics have been drawn up to define the level at which the students have met the objectives set out in paragraph 2.2. The grid used to judge the active teaching experience is explained in paragraph 4, at the end of the presentation of the teaching application.

On the basis of the learning outcomes described in paragraph 2.2, the teachers have designed the classroom lessons and the written exam with the aim of developing points 2, 3 and 4 of the learning outcomes, whilst the active teaching experience and the assessment table A1 are aimed at developing points 1, 5 and 6.

The organisational and evaluation approach shown in paragraphs 2.3 and 2.4 also features in the course provided at Politecnico di Milano with a few differences: the architectural structures on which the exercises are carried out have been chosen both as a significant example of a structure and as an example aimed at the studio topic (Architectural Design Studio) that the students are developing; the active learning part is extended to the architecture project developed in the interdisciplinary studio, with

continuous communication between student and lecturers of different disciplines in order to get a project which is sustainable in a range of different aspects (compositional, structural, technological and installation-wise) and the final evaluation also includes an assessment of the student's ability to work with others when tackling an architecture project.

3 Active Learning Experience

In the application of active teaching shown in this paper, the students are invited to study a fairly complex Structural Engineering problem: the lateral instability (i.e. lateral-torsional buckling) phenomenon of beams. For a better understanding, the activity has been divided into three stages: stimulus, practice, discussion (St-Jean, 2001).

3.1 Stimulus

First and foremost, in order to build an effective didactic activity, it is necessary to organise the course in a stimulating and challenging way (Bonwell and Eison, 1991; Lumpkin et al. 2015). This is the most difficult, time and energy-consuming part for educators: looking for a complex, interesting topic, and turning it into an efficient tool for learning actively. Since, according to the authors' experience, architecture students seem not to be motivated by demanding structural problems (e.g. long span beam analysis, unusually loaded walls), the experience here proposed turned out to be successful in stimulating students' curiosity and promoting learning of a complex phenomenon such as the lateral instability of beams. Lateral-torsional buckling in architecture courses is usually explained using simple examples (i.e. Euler theory for slender columns) and without a proper understanding of the theory behind the instability phenomenon. As a matter of fact, a traditional, passive explanation of the subject, such as the one used for civil engineering students, would be ineffective for

most of the architecture students due to their lack of adequate prior mathematics knowledge (Sgambi et al. 2012; Arefi & Hadian, 2013).

The method adopted with the students of Politecnico di Milano and Université catholique de Louvain is unconventional: after being divided into 11 teams of about 10 people, each group was presented with a gridded silicon pot mat (still available for sale online; Fig. 2) and was challenged to 1) describe and qualitatively explain the physics phenomenon observed when bending by hands the pot mat; 2) demonstrate that what was observed was, in fact, a case of instability; 3) think about solutions to be adopted on a real structure.

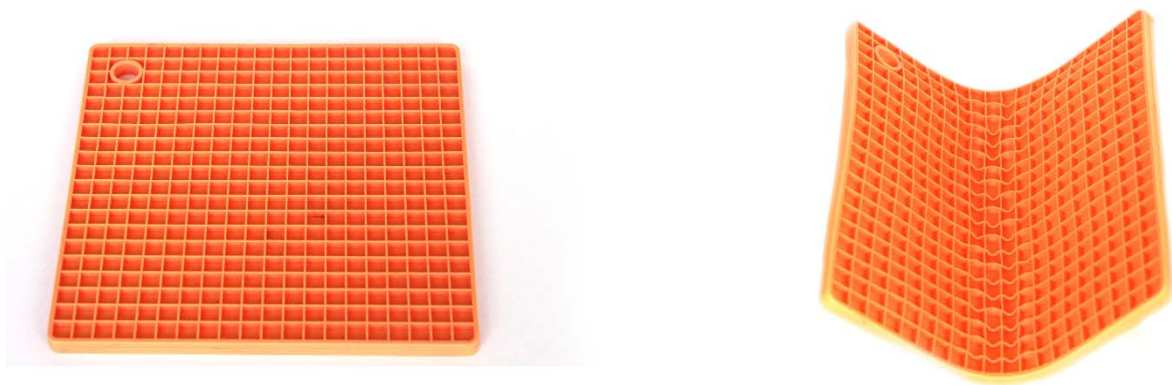


Figure 2. Square silicon pot mat consisting of a grid of plates and a horizontal membrane. The right figure shows how the instability phenomenon affects some of the plates.

After an initial, reasonable disorientation, most of the students became enthusiastically engaged in the experiment. The opportunity of experiencing the physics phenomenon for real and the structural affinity of the pot mat model with existing structures such as the famous New National Gallery di Mies van der Rohe (Fig. 3) gave the students the right motivation.



Figure 3. The "Neue Nationalgalerie" (New National Gallery), Mies van der Rohe architect. Image released into the public domain by its author Oliver Löffler.

The first question (i.e. describing and explaining what has been observed) is only apparently an easy task. It hides some tricky topics of civil engineering and architecture (e.g. nodal equilibrium, behaviour uncertainty, structural modelling) as well as advanced considerations beyond the students' level of knowledge. Therefore, the teacher has the responsibility of guiding and supervising the learners throughout the entire process. The second challenge (i.e. defining a "theory" to describe the phenomenon) looks banal as the students are asked to demonstrate what they see. However, the challenges here are to conceive a simplified theory to explain the lateral instability with the help of the instructor-tutor and to design and perform some experimental tests as real researchers. The third task (i.e. finding methods to solve the

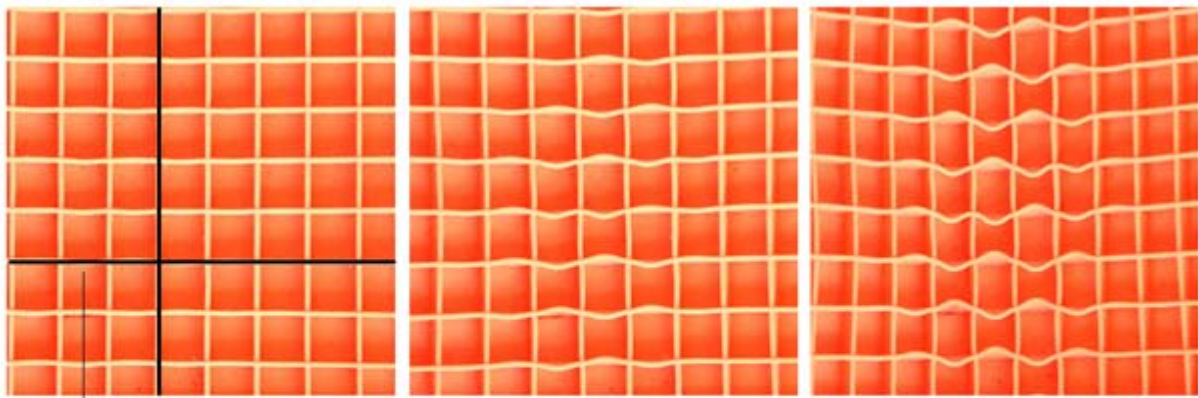
problem in a real structure) connects the empirical experience to the reality of an existing structure. Because lateral-torsional buckling might occur in large structures (e.g. steel beam and steel truss), basing on what they have learnt from the first two assignments, the students have to suggest solutions that can be applied on a civil engineering structure.

3.2 Practice

The students are divided into large teams in order to facilitate group discussions. Furthermore, since the experience involves statistical treatment of data for the definition of the material mechanical properties of the pot mat, the more people there are, the more data samples can be collected.

The first question usually results in a reasonable amount of observations. There is no substantial difference in the percentage of answers between students from Politecnico di Milano and the ones from Université catholique de Louvain. The 5 most significant observations are shown below. As shown in Figure 3, due to the gridded structure of the pot mat, the plates are classified as longitudinal (i.e. elements subjected to lateral instability) and transversal (i.e. elements normal to the longitudinal ones).

- 1) 100% of the groups recognise that the instability phenomenon affects the longitudinal plates in the middle concave portion of the grid (Fig. 4) and thanks to prior knowledge of Euler-Bernoulli beam theory, they can provide explanations for it (Fig. 5).



« Transversal » rib (deforming with no instability)

« Longitudinal » rib (deforming with lateral instability)

Figure 4. Lateral-torsional buckling affecting longitudinal elements of the grid as it appeared to students.

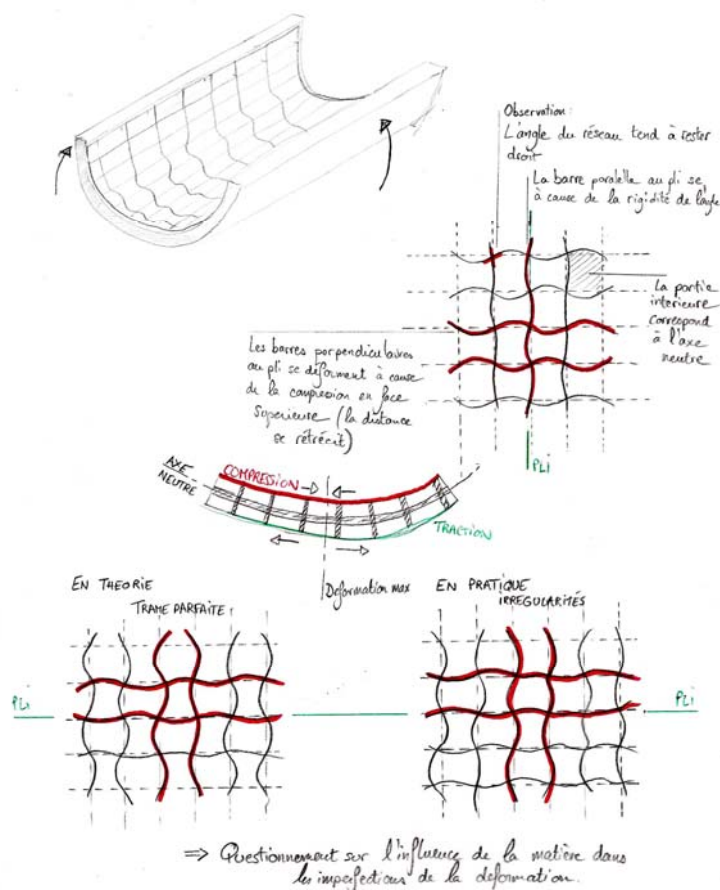


Figure 5. Explanatory schemes made by students from Université catholique de Louvain.

- 2) 100% of the groups observe lateral displacements in the “longitudinal” ribs affected by instability, but none of them is able to give a proper explanation. Some teams misjudge the direction of displacement as random.
- 3) 100% of the groups notice that the instability does not influence the side ribs. The teams correctly hypothesised that the resistance to the phenomenon is related to the perimeter-rib cross-sectional area (about 3 times thicker than the inner ones) and the higher moment of inertia.
- 4) 100% of the groups detect a certain deformation also on the “transversal” elements (Fig. 4), but none of them was able to justify it. 50% of the teams erroneously relate the effect to a similar instability phenomenon. Based on the bending moments transmitted from the deformed longitudinal members to the cross ones at the joints, one group is able to correctly interpret the lateral-torsional buckling (Fig. 6).

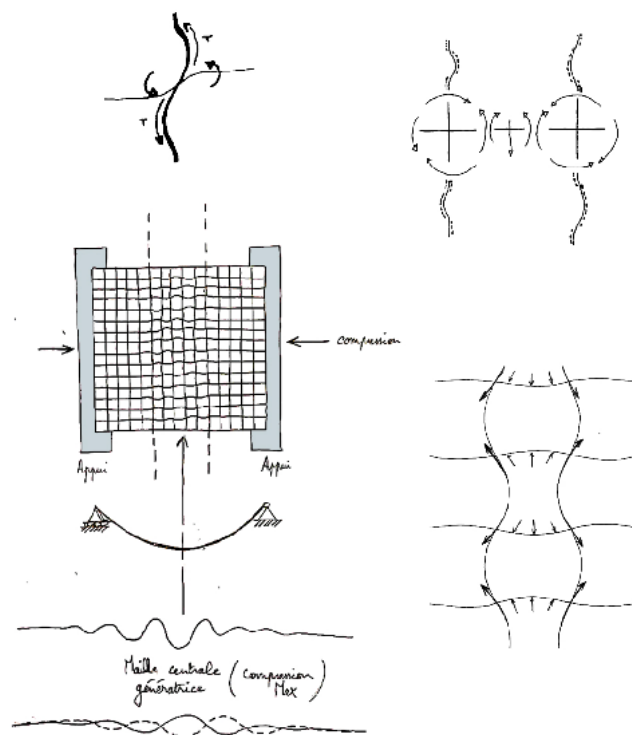


Figure 6. Schemes made by students to explain the lateral displacement occurred in the transversal elements based on the transmission of bending moment at the plate joints.

- 5) 40% of the groups find out that both longitudinal and transversal members are connected by a two-dimensional thin membrane. The remaining 60% of the teams stay stubbornly focused exclusively on the behaviour of the ribs. Only 20% of the groups recognise that this membrane lays in the barycentre of the grid elements, therefore it doesn't affect the bending action.

At the end of the observations, the teacher-tutor explains how the lateral instability of the whole rib in the compression region can be approximated to the Euler instability (i.e. the only tool students learnt from previous traditional structural classes) limited to its upper portion (i.e. $1/3$ of the rib's total height has been hypothesised to be affected by buckling).

In order to apply the Eulerian theory, it is necessary to know the material Young modulus, E . Therefore, by designing and assembling on their own a testing machine to perform simple tension tests on the silicon pot mat, the students obtain the material's mechanical properties. Figure 7 shows few of the tensile testers built up.

At this stage, students are free to be creative; only a small amount of basic information about the possible development of the experiment is given to them. Simple, ordinary items are used: a ruler for measuring the deformations, strips of wood or metal flat bars and butterfly screws as clamp and a luggage weighing scale as dynamometer for measuring the axial load during the test. As prescribed by the Building Code, in order to obtain statistically valid data samples, each group has to perform at least fifty measurements.

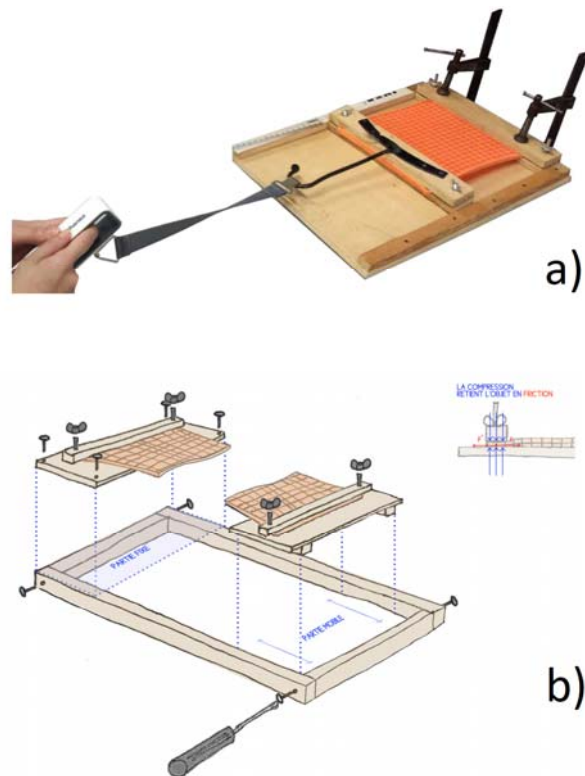


Figure 7. a) represents a testing machine created by students of Politecnico di Milano; b) is a similar tester designed by students from Université catholique de Louvain (Tournai campus).

During the experimental analysis, for safety reasons and for taking advantage of the small deformation theory (i.e. domain used to estimate material mechanical properties such as Young modulus, E), students were advised not to trespass the threshold loading of 5 cm. However, students usually decide to take it further in order to test the deformation limits of the material. By doing that, one team out of the eleven (i.e. 10% of the groups) considered in this study has noticed a secondary effect related to the phenomenon of lateral instability affecting the ribs normal to the direction of elongation (Fig. 8).

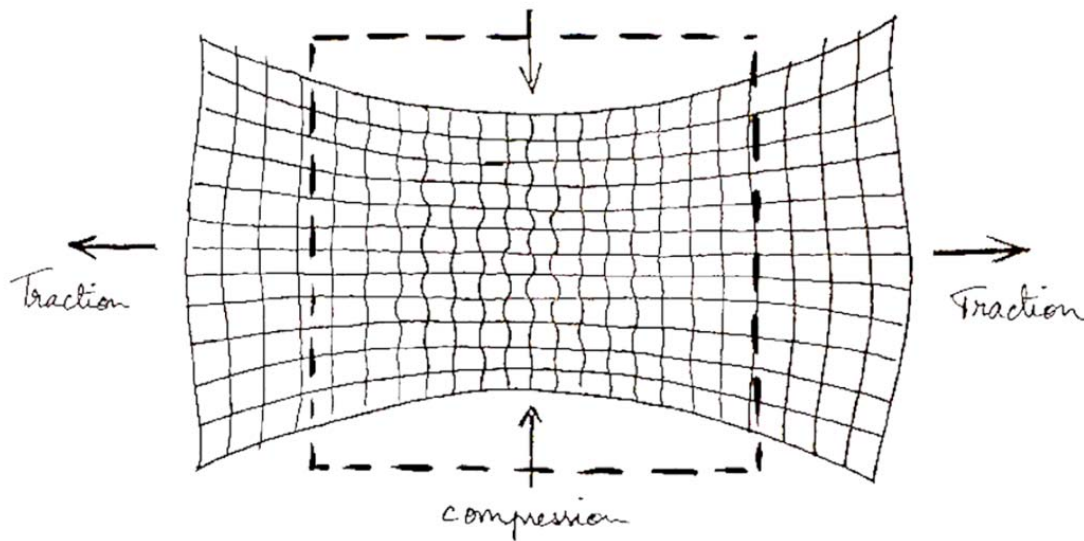


Figure 8. Example of instability affecting the bi-dimensional membrane due to overextension and transverse compression (Poisson effect).

This observation has generated an interesting, unpredicted class discussion. According to *observation 5*) previously mentioned, when it comes to the lateral instability caused by bending the pot mat, the two-dimensional thin membrane which joins all the ribs doesn't influence the overall behaviour. However, when the mat is stretched, the same membrane undergoes extension and contraction due to Poisson effect. The transverse compression causes the ribs to contract with the membrane. Therefore, for high values of elongation, the ribs normal to loading direction are subjected to instability. This consideration demonstrates the efficacy of active learning experiences in motivating the students to develop their creativity and critical thinking even above and beyond the initial expectations.

3.3 Discussion and quantitative analysis

In the third and final part of the experience, the students, with the support of the teacher, collect and process all the information and data (quantitative analysis) from the previous steps and discuss the results.

Although the initial observations from the visual description of the physics phenomenon in task one (see par. 3.1) appear to be interesting, they don't answer the main problem. In a parallel with the architectural field, it would be the same as asking a student to talk about the architecture of a building and to receive a response with visual details and elementary deductions (e.g. there are large windows for maximising natural lighting; there is a gable roof for facilitating water flow). Only people with an advanced knowledge, such as the teacher-tutor, can fully answer to the first question. He/she has to be able to analyse all the observations, process them and make the right logical connections in order to explain the physics phenomenon. As a matter of fact, the link between observations (Bateson, 1979) is the key to solving task 1). When the pot mat starts to bend, the ribs are compressed, generating lateral instability (observation 1, par. 3.1). If the structure was ideal, the lateral displacement would be more likely to happen in one or another direction with the same probability. However, in a real structure, the weaker element causes the structure to shift according to the less resistant direction. If there are no shape imperfections in the material (observation 2), when one portion of the rib undergoes instability, the remaining areas will follow with a wavy path (Fig. 4). Due to their instability, the "longitudinal" members activate a torsional force on the node which causes the "transversal" elements to bend with a scheme related to the "longitudinal" ribs' pattern (in absence of imperfections; observation 4, par. 3.1). While progressively damping approaching the perimeter of the mat, the lateral-torsional buckling spreads to a wide area (observation 5, par. 3.1). Therefore, if the pot mat were "ideal", even one element affected by instability would

define the whole deformation pattern and waveform symmetries and mirroring would be always verified. But because of the imperfections in the real structure, complex behavioural exceptions occur that students cannot explain (observation 2, par. 3.1).

At the end of the qualitative analyses and when they have understood the phenomenon, the students are invited to analyse the data gathered during their experimental tests to calculate the characteristic value of Young's modulus (E in Eq. 1). During the experimental tests, the students gather several value pairs of force (F) with related extensions (ΔL). On the basis of these values, the stress (σ) and axial deformation (ε) are measured. The stress is measured by dividing the measured force by the area of the section of the pot mat (314 mm^2), while the deformation is obtained by dividing the extension, ΔL , by the length between the terminals of the test machinery (L). The relationship between these two values is then carried out to obtain Young's modulus of elasticity (Eq. 1).

$$\sigma = \frac{F}{A} ; \varepsilon = \frac{\Delta L}{L} \rightarrow E = \frac{\sigma}{\varepsilon} \quad (1)$$

As the process of measuring is repeated around fifty times removing and repositioning the pot mat in the test machinery, the uncertainty related to the measurements leads to get a set of values of Young's modulus (E) which should be studied from a statistical point of view, just as the results of a laboratory analysis for the characterisation of a material usable in civil engineering. Figure 9 shows the Young's modulus (E) data collected by one of the groups of students during the experimental tests, in form of a histogram.

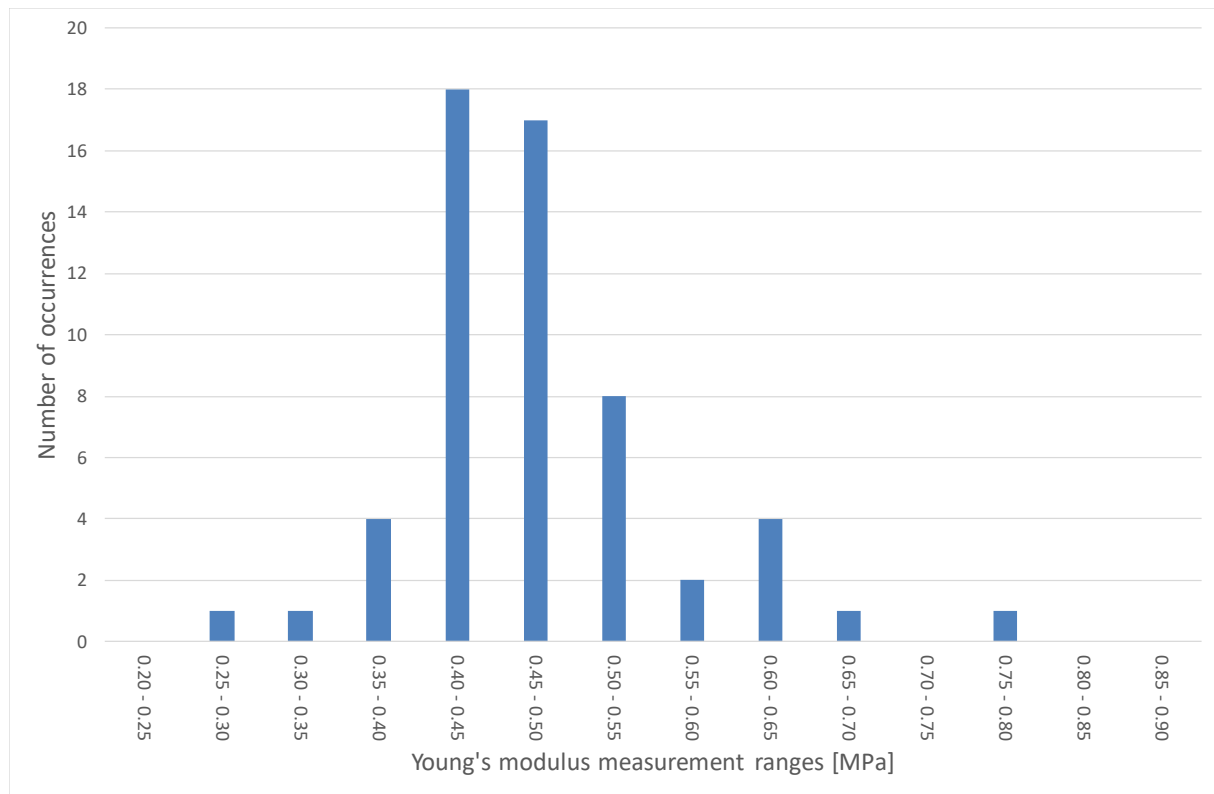


Figure 9. Histogram of the values of Young's modulus.

The statistical analysis of data is carried out with the help of a spreadsheet with which the students can estimate the average value and the characteristic value (i.e. representative value which has a 95% probability of not unfavourably exceeding the actual one) used for the structural checks (in the case in question $E_k = 0.2405$ MPa).

At this stage, the students carry out the stability check according to the loading condition shown in Figure 10 (pot mat on a basic support with the distance L between the supports of 15 cm). The nomenclature for the variables and the dimensions required for carrying out this check are summarised in Figure 11: height of the rib ($h_r = 8$ mm), distance between the ribs ($L_r = 8$ mm). For the sake of clarity, a subscript "pm" (length or side of the pot mat $L_{pm} = 18$ cm) is assigned to the variables relating to the entire pot mat, whilst a subscript "r" (length or rib span $L_r = 8$ mm) is assigned to the dimensions relating to the ribs (Fig. 11).



Figure 10. Loading condition for the pot mat.

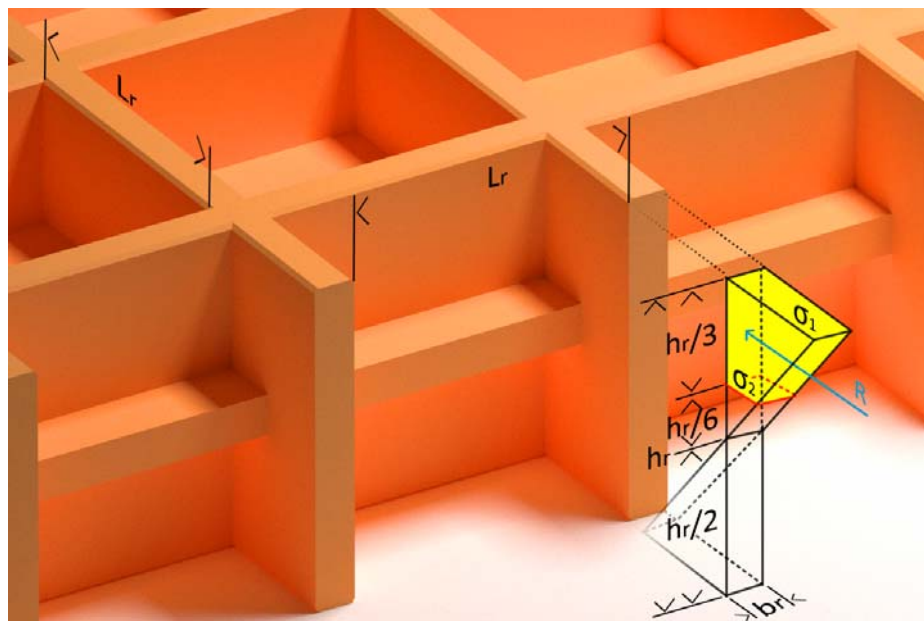


Figure 11. Nomenclature of the dimensional variables used to verify the stability.

As the students do not have the basic knowledge for understanding the equations governing the problem of the lateral instability of the beams (a system of three coupled linear differential equations) the teacher, together with the students, devises an approximate verification method based on the observations listed in par. 3.2 and on Euler's stability theorem (which the students have studied in earlier courses). In this method, it is assumed that the upper part of the ribs (one third of the height of the pot mat in Figure 11) is not restrained by the lower part. This hypothesis, which is always

compelling for higher safety standards, is also justified by the high level of deformability of the silicon used to form the pot mat.

To perform the stability verification, compression force R acting on the upper part of the pot mat must be assessed before anything else. To start with, the distributed load q (Figure 11 on the left) is calculated dividing the weight P (0.981 N) of the pot mat, by its length (L_{pm}), which is equal to 18 cm.

$$q = \frac{P}{L_{pm}} = \frac{0.981}{180} = 0.00545 \text{ N / mm} \quad (2)$$

The maximum bending moment (acting in the middle) can be obtained by using the formula which assesses the bending moment in the middle of a beam subjected to a distributed load (Eq. 3). It should be noted that the value obtained in this way is relative to the entire pot mat and should be divided by 21 (number of ribs in the pot mat) to estimate the value of the maximum bending moment on each individual rib.

$$M_{pm} = \frac{q \cdot L^2}{8} = \frac{0.00545 \cdot 180^2}{8} = 15.33 \text{ N} \cdot \text{mm} \quad (3)$$

$$M_r = \frac{M_{pm}}{21} = \frac{15.33}{21} = 0.7299 \text{ N} \cdot \text{mm} \quad (4)$$

Next, taking into consideration the formulae of De Saint Venant relating to bending (learnt in previous courses), the students are able to identify the magnitude of the maximum tensions on the section of the rib (σ_1) and of the tensions which lie at a third of the height (σ_2) making a simple ratio on the trapeze visible in Fig. 11:

$$\sigma_1 = \frac{M_r}{W} = \frac{0.7299}{\left(\frac{1 \cdot 8^2}{6} \right)} = 0.06843 \text{ N / mm}^2 \quad (5)$$

where $W = b_r \cdot h_r^2 / 6$ is the modulus of resistance of the section, b_r is the base (width) of the rib (1 mm), whilst h_r is the height of the (8 mm).

$$\sigma_2 = \frac{\sigma_1}{3} = 0.02281 \text{ N / mm}^2 \quad (6)$$

The compression force R , acting on the upper part of the rib (Fig. 11) can therefore be assessed by calculating the volume of the solid of the tensions (prism with a trapezoidal base):

$$R = \left(\frac{\sigma_1 + \sigma_2}{2} \right) \cdot \frac{h_r}{3} \cdot b_r = 0.1217 \text{ N} \quad (7)$$

where $b_r = 1$ mm (width of the rib) is the height of the prism with a trapezoidal base. If we now assume that the outstretched lower part does not contribute towards preventing the upper part listing because of instability, a critical compression load can be estimated using the Euler formula (Eq. 8):

$$P_{cr} = \frac{\pi^2 \cdot E_k \cdot I_t}{L_r^2} = \frac{\pi^2 \cdot 0.2405 \cdot 0.2222}{8^2} = 0.002469 \text{ N} \quad (8)$$

In which I_t represents the inertia of the trapezoidal upper part of the rib subject to the phenomenon of instability, assessed as:

$$I_t = \frac{b_r^3 \cdot h_r / 3}{12} = \frac{1^3 \cdot 2.666}{12} = 0.2222 \text{ mm}^4 \quad (9)$$

It should be noted that, in Eq. 9, the elevation to the cube is on the dimension b_r since the phenomenon of instability checked is perpendicular to the height of the ribs (along the direction with the weakest inertia). It is worth noting therefore how critical load value P_{cr} (0.002469 N, Eq. 8) is 72 times less than load value R (0.179 N, Eq. 7) which is

present in a situation where there is pure flexion, which justifies the appearance of the phenomenon of instability.

To finish the exercise, as requested by the third challenge (see paragraph 3.1), the teams have to apply what they have learnt to a real structure. The most frequent solutions suggested were: evenly increasing the elements' cross-section (Fig. 12a); adding a wing to the compression ribs and turning the rectangular section into T-shape (Fig. 12b); adding a bracing system (Fig. 12c). All the solutions attempted have a positive validation in commonly adopted strategies for structural design.

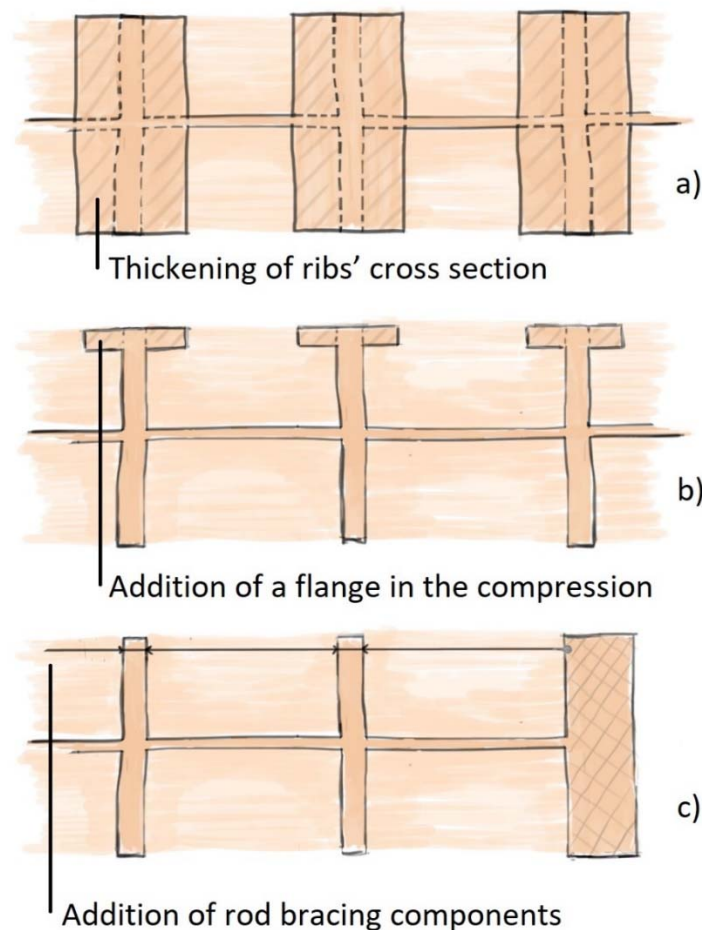


Figure 12. Three proposals made by students to solve the lateral-torsional buckling: a) increasing ribs' cross-sectional area (original elements are shown in dashed lines); b) turning ribs' rectangular section into T-shape (original elements are shown in dashed lines); c) adding a bracing system to connect the compression part of the inner ribs (thinner el.) with the perimeter rib (thicker el.).

4 Assessing students' work

As detailed in paragraph 2.4, the students must present a table in A1 format which displays, in both a graphic and textual version, a complete summary of the task performed. The assessment of the students' work is carried out using a rubric (Stevens and Levi 2005, Onsmann 2016, Gregori-Giralt and Varela 2018) prepared before the start of the course, which is shown to, and discussed with, the students on the first day. A rubric is a guide which makes clear to the professor and students what the professor expects from the work and how it will be evaluated. A rubric essentially consists of three parts and can be represented in the form of a table (Fig. 13 and Fig. 14) containing: the performance criteria, the scale of assessment and the indicators.

Rubric of assessment – Pot Mat experience				
Scale of assessment	The student must be able to formulate and criticise...	The student must be able to converse in a professional manner...	The student should be able determinedly to pursue the implementation...	Originality and the creativity of the composition of the table A1
Not acceptable	The student has carried out no observations (not even those discussed in the classroom) and has made no criticism.	In the table submitted, there is no design drawing and the technical terminology used is not correct.	The test appliance has not been constructed and the experimental analyses have not been done.	The presentation is not complete, fundamental parts are lacking such as the observations, the test machinery or the checks.
Insufficient	The student has only made less than 30% of the observations and criticisms identified by the teacher (paragraph 3.2).	The drawings used in the table submitted are not complete and the information which is lacking is important for understanding the structural thinking.	The test appliance has not been constructed but the analyses have been performed using the appliance constructed by another group of students.	The presentation is complete but the different parts of the work have not really been linked together.
Sufficient	The student has made at least 50 % of the observations identified by the professor and has been able to explain them and criticise them in an appropriate manner.	The drawings used are graphically acceptable and complete. The explanations use the correct terminology, there are no spelling or grammatical errors and the concepts have been understood immediately.	The appliance has been constructed and, in the table submitted, there is an explanation of the idea of the concept of the appliance and photographs of the final creation. The experimental analyses have been accurately performed.	The presentation is complete and clear. The method of presentation is traditional and sequential.
Good	The student has made all the observations identified by the professor, explaining them in an appropriate manner.	All the requirements found in the preceding point, with the added bonus of the presence of explanations in all stages of the work (observations, concept of the test apparatus, experimentation, checks).	All the requirements found in the preceding point, together with all the information for constructing the test appliance (materials, dimensions, assembly etc.).	All the requirements found in the preceding point. Additionally, some parts of the presentation have been structured in an original way.
Excellent	The student has managed to make observations which the professor had not even thought about; the student has managed to put together the observations made (par. 3.2).	All the requirements found in the preceding point together with references to the workplace of the engineer or architect (mentions of Eurocodes, actual buildings, etc.).	All the requirements found in the preceding point, together with some criticisms of the appliance constructed in the light of the experimental analyses done and some ideas as to how to improve the appliance's performance.	All the requirements found in the preceding point, together with the use of methods learnt on other courses during their studies.

Figure 13. Rubric used to assess the work of the students.

Follows a description of the four performance indicators used to assess the work of the students. As well as the three indicators shown in paragraph 2.4, the teachers have added a fourth parameter to represent the originality and creativity of the composition of the A1 table in question.

The final evaluation of the work is carried out using an overall interpretation of the rubrics, according to the performance achieved in the different criteria. It is important to emphasise the presence of an unacceptable level which leads to the refusal of the work even if the assessment occurs in only one of the criteria. Lastly, it is important to emphasise that the same weight is not given to all of the criteria. When this experience is being judged, more weight is given to the first two criteria which are considered to be more important in relation to the course program.

EXERCICE 2
SOUS PLAT

Horstemeier (Clerge) | Adrien (Debray) | Maxime (Ducrocq) | Tom (Lambert) | Aurélien (Michelet) | Mikaela (Oudry) | Luc (Pelland) | Victoria (Segin)
Université Catholique de Louvain | 1050 Tervuren | Mars 2022

1

OBSERVATIONS DU COMPORTEMENT ET ANALYSE

Compression / Traction

Effets internes

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

Flambement

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

Déformement

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

Transmission normale

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

Transmission tangentielle

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

Réactions d'équilibre de la maille

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

États de la matière

Quand une poutre est soumise à une charge, elle se déforme. Cette déformation se traduit par une compression ou une traction. Les effets internes sont les forces qui s'exercent à l'intérieur de la poutre pour résister à la déformation.

2

CONSTRUCTION DE L'APPAREIL DE MESURE

Le but de cet exercice est de construire un appareil de mesure capable de mesurer la force appliquée sur un échantillon de matériau. L'appareil est composé d'une poutre horizontale, d'un support vertical, d'un poids variable et d'une échelle de mesure.

3

MESURES

Le but de cet exercice est de construire un appareil de mesure capable de mesurer la force appliquée sur un échantillon de matériau. L'appareil est composé d'une poutre horizontale, d'un support vertical, d'un poids variable et d'une échelle de mesure.

4

CALCULS

Le but de cet exercice est de construire un appareil de mesure capable de mesurer la force appliquée sur un échantillon de matériau. L'appareil est composé d'une poutre horizontale, d'un support vertical, d'un poids variable et d'une échelle de mesure.

5

CONCLUSION

Le but de cet exercice est de construire un appareil de mesure capable de mesurer la force appliquée sur un échantillon de matériau. L'appareil est composé d'une poutre horizontale, d'un support vertical, d'un poids variable et d'une échelle de mesure.

Rubric of assessment – Pot. Mat experience				
Scale of assessment	Performance criteria 1	Performance criteria 2	Performance criteria 3	Performance criteria 4
Not acceptable				
Insufficient				
Sufficient				
Good				
Excellent				

Figure 14. An example of a submitted table and use of the assessment grid.

5 Feedback

At the end of the course at Université catholique de Louvain, students were asked to evaluate the course, providing opinions and suggestions to help improve its content and teaching aspect.

The results of this survey showed that 83% of students found that the structural engineering material was difficult to understand for an architecture student, 97% of students appreciated the use of examples of real architectures in the explanations of new structural engineering concepts, 87% of students appreciated the introduction of an active teaching experience and 97% of students in general liked the course.

As regards the experience undergone at Politecnico di Milano, it was not possible to gain such detailed feedback as the verdict expressed was all for work carried out within the Studio Design. However, the general appreciation was positive both with regards to the active learning experience itself, and for the methodological approach which was also extended to the discussion and understanding of structural problems faced in architecture projects.

Reading the comments about the active teaching style, there appears to be a certain amount of enthusiasm, on the part of students, for putting themselves in the shoes of a researcher, looking at an unknown phenomenon, trying to understand it, explain it and speculating on mathematical rules for interpreting it. There are some negative comments, mainly regarding the size of the working groups (10 students). It is true to say that such numerous groups do lead to organisational difficulties for taking the work forward outside lesson hours.

6 Conclusion and comments

The article concerns the introduction of an active teaching experience in a Structural Engineering course provided in a School of Architecture. After having investigated the learning outcomes required by the study program, the article analyses the structure of the course and the motivations which inspired the authors to introduce this experience into a course built on the basis of a passive teaching style. As has been highlighted by various authors (McCrum 2016, Kersten, 2018), an active teaching style stimulates the development of critical thinking and creativity, features which are essential in today's world of work (Zernike 2009).

The activity described in this article is based on a qualitative and quantitative analysis of the phenomenon of lateral instability of beams. This subject has been chosen in order to put architecture students in the position of having to study a phenomenon for which they do not have the fundamental mathematics and physics knowledge to be able to follow the natural discussion about it which takes place in a structural engineering course (typically, basic mathematics to formulate and solve a system of differential equations). This motivation is essential: teaching methodology cannot be formulated in a deductive manner (without the fundamentals to formulate the axioms from which to draw the demonstrations and general rule). It should be formulated in an inductive manner, overturning the learning strategy. The students are first invited to observe and comment on the behaviour of a silicon pot mat (currently on sale on the web) which displays lateral instability. They are then asked to examine the effects of it quantitatively, constructing a simplified theory on the basis of structural mechanics theories already studied in other courses (balance of isostatic structures, instability of Euler). In order to put this approximate theory into practice, the students are invited to construct by themselves a small test machine, to assess Young's elasticity modulus on the silicon used to make the pot mat. This phase of the work leads students to be

confronted with actual problems found in the laboratories in which mechanical tests on structures are carried out (uncertainties in the measurements, emergence of secondary bending moments, forces applied off-axis, etc.). The statistical discussion on the data obtained is useful for understanding the probabilistic aspect in all of today's technical legislation.

Going back to the thoughts of Zernike (2009), the authors are firmly convinced that the introduction of such an activity, as also for other active teaching methods, in a course based on the passive pedagogic philosophy, can stimulate Architecture students into developing critical thinking with regards to structural problems.

Although 83% of students on the course at Université catholique de Louvain, described the topics dealt with in the course as being very complex and difficult to understand, 97% of them appreciated the educational organisation, the way the lessons were structured based on actual examples and the alternation between passive learning, exercises and active teaching methods. Meanwhile, the students at Politecnico di Milano also appreciated the opportunity of extending the method of investigation to structural problems faced in the Architectural Design Studios or in the thesis.

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