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Glued-Wood Structure Development Contests for Project Based Learning in Engineering and Architecture Degrees*

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The contests involving the development of glued wood structures represent a motivating challenge for the students. These activities are rightfully included in the field of active learning or Project Based Learning. The advantages of these kind of contests is its low cost, especially when compared to other similar contests such as Formula SAE or others. This makes these competitions affordable to all students. Furthermore, these competitions are more civil engineering oriented. Surprisingly enough, in most of the competitions the academic performance has a lot of room for improvement. This is mainly due to the fact that they were considered more as a promotional event than a useful teaching tool, especially in the first editions. In the work presented in this paper, the technical aspects of these contests have been studied in order to improve, as much as possible, the learning aspect of those events. In order to do so, a review of the current state of the art in those contests is performed. After that, some technical considerations on the possibilities that those contests allow are developed. This is done while keeping, as much as possible, the reduced costs of these events. After that, the recommendations have been put into practice in a real scenery and some conclusions are exposed. This has been made via a pilot experiment where a student has been asked to analyze the glued-wood structure that it was developed by him in a contest.

Keywords: active learning; structural analysis; bridge models; glued wood; educational model contests

1. Introduction

Active learning or Project Based Learning (PBL) methodology can be considered as one of the most appropriate educational methods for the development of competences linked to the professional future of the student when associating, both content and the context [1–4]. It is a methodology in which the student learns to make decisions and solve concatenated problems of analysis, design, calculation and construction, in this case, of structural systems for building and civil works. The methodology assumes the adoption of a certain autonomous direction of each work. At the same time, it involves an open teaching, centered on motivation, from situations that arise from the appearance of problems. The proposed activities and those developed finally, presuppose that the relationship among student and teacher is such that it is established in environments defined by criteria such as, for example:

- Emergence of an individual enthusiasm in the student, directly involved in the work and collective as an individual belonging to a group, course or class, in this case [5].
- Flexibility for deciding what you want to learn.
- Delimiting the paths to knowledge.
- Establishment of problems that become challenges in which to apply knowledge.
- The promotion of autonomy in order to enhance cross-cutting and specific competences [6–8].

During the development or elaboration of the End of Degree Project and, by extension, of the Master's Degree Thesis, especially those that refer to structural and constructive systems, the student is forced to adopt methodological simplifications due to limitations of material means and time. However, it is necessary to get used to the decision-making process involved in the evaluation of the different alternatives in the analysis of systems and materials mainly, as well as to adopt a method of using tools, for example, of calculation that will necessarily have to be assumed during the professional career. In order to improve the attitude of the student it is interesting that these developments are framed in a game or leisure context. This will lead to better learning and greater acquisition of knowledge (see [1]). This can be done by establishing this part of the teaching in a context of participation in a public contest among students, encouraging competition among partners, stimulating the imagination in the approach of the solution and strengthening the leadership in front of the group. These type of contests are not new. Thus, one of the oldest is the Formula Student (derived from the SAE Formula), in which students design and tune up a competition vehicle with which they compete in a race [6]. Similar competitions are the Shell Eco Marathon [7], which aims to cover as much distance as possible with a given amount of fuel or Motostudent [8], similar to the Formula Student but in which the students have to design a competition motorbike. In the aerospace sector the Air Cargo Challenge [9] or CubeSat [10].

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Some of these competitions with relevant data for comparison purposes are included in Table 1. All of them achieve this goal, although all of them present the same cost of participation problem, which is usually sponsored by private companies. This is of a great advantage, because this approach allows to overcome one of the biggest problem that appear on Project Based Learning, which is the cost (see Table 1). One could also state that another way to solve the problem is the frameworks of collaboration with firms, but in practice these do not reach to all of the students and in most cases the students are presented in the firms with problems that are trivial or lack motivation. Another problem is the lack of homogeneity that is inherent to firm collaboration. This is due that the nature of the collaboration heavily depends on the firm. A last problem with these collaborations is that they are only successful when applied in the later years of formation and, thus, are not applicable to subjects such as basic analysis of structures.

The proposal that is formulated in this article tries to pose, from a contest of structures in general or of bridges in particular, a playful activity and, at the same time, a tool to learn how the structure works internally in a practical way, complementary to the (in the other hand necessary) classic learning routine of blackboard theory classes and purely theoretical problems. Finally, proving that the theoretical developments learned during the Degree lead to obtain real information and gives the student great confidence in himself. A great advantage of this approach is that the real cost of participation is extremely low (as exposed in Table 1), which allows nearly all students to participate, as long as they have some time to dedicate. As will be explained later on, toothpicks built-in structures, in general, or bridges in particular, contests are not a new idea, but in many occasions these competitions are not posed in an efficient way from the teaching point of view, because the competition and /or the show are favored over learning. The objective of this writing is, first of all, to study different structure-contests of this type all over the world, analyzing the interesting aspects from an educational point of view. Then a number of ideas will be proposed in order to enhance the educational side of these contests. Next, the steps that (in the opinion of the authors) should be followed by the organization in order to put these ideas into practice will be defined and, finally, experimental data will be provided from a particular case. This particular case includes, in one hand, the preparation work that should be made by the organization and, in the other hand, an example of the analysis that should a student do. In this case, the authors of this document asked a student to analyze the structure he built in an already finished contest.

2. Popsicle stick bridge contests

Glued-wood structure construction contests (usually bridges built with toothpicks or pallets) are a widespread practice throughout the world. Important advantages of this type of contests are the low cost of participation (due to the low cost of materials), low risk and, additionally, the fact that they are attractive to viewers, which, consequently, have an important advertising effect. Numerous references can be found, that propose the modeling, construction and testing of a structure as an educational activity. Before analyzing them in detail, we will point out some common aspects that characterize the different proposals that have been found. The context is, generally, the teaching of theoretical concepts and calculation of structures enclosed in civil engineering and similar degrees. It is easy to find examples in which models are used by teachers as a support to highlight basic concepts such as stress, deformation and others related. However,

Table 1. Some of the most popular University Competitions

Competition Name	Approximate team size	Approx. Required Budget to participate (euros)	Scope	Engineering Areas Involved
Popsicle Building Contests	1–5	From 20 to 100	Local/National	Civil and Construction
Formula Student	15–50	From 20000 to 1000000	International	Mechanical, Electrical, Electronic, Engines, ...
Moto Student	7–15	From 5000 to 40000	International	Mechanical, Electrical, Electronic, Engines, ...
Shell Eco Marathon	15–30	From 20000 to 50000 (estimated from regulations)	International	Mechanical, Electrical, Electronic, Engines, ...
Air Cargo Challenge	3–6	From 1000 to 5000 (estimated from regulations)	International	Aeronautical, mechanical, Electronic, Electrical
CanSat	3–10	No data available	International	AeroSpatial

nowadays the main objective pursued in students by modeling and testing, based on practical cases, is educational, this way the participation of the student, individually or in a group, is a basic and necessary condition. On the other hand, these type of experiences usually go paired with the celebration of a contest; therefore, to a competitive and overcoming environment among students. In the research carried out, it can be seen that, the structural typologies that prevail among all are those that functionally save a span in the shape of bridges, of very varied typologies and functionalities. The complexity of the bridge varies enormously and goes from simple supported boards, to panels complemented by lattice structures, especially arches, with or without additional cabling. They are structures that must guarantee minimum and maximum dimensions, together with weight limitations, including the weight of the bases that support the complete structure. Inside these limitations minimum dimensions of the span are also necessary, guaranteeing a minimum space under the bridge. Normally the supports of the structure are all in the same plane. However, there are proposals in which participants are asked to work with asymmetrical supports (see ASCE L.A. [11]). It must be highlighted that the loads in these contests are usually vertical loads applied in the center of the span of the structures. On the other hand, the objective of these tests is usually, to determine the maximum load the structure can withstand, making it collapse. It is not rare, neither, to have a special prize dedicated to the aesthetic side of the structures. The materials used in the different contests vary in a wide range, being the most common one wooden pallets or toothpicks, like the ones used for producing popsicles, stack together with some sort of adhesive, habitually white wood glue or simply, white glue. Picturesque alternatives can also be found, such as the use of straws (the ones used for drinking soda) or Italian "pasta". These contests or experiences are used at all educational levels. Starting at scholar scope, and as a way to introduce students to hand craft and technologies, especially at Secondary School and Professional Formation levels. As one can expect, this document is centered on University level contests, which are plentiful. Besides the contests, it is easy to find these type of tests as a way to overcome subjects at University, though, most proposals have a playful orientation. According to geographical and cultural distribution, it cannot be said that these tests or events are carried out at a certain geographical area. During this study, examples have been found in Anglo-Saxon countries, Spanish and Portuguese speaking countries and, not only in the West, but also in certain Asian and African locations. These contests are carried out in an annual basis, and it is easy to find cases in which they have been active for more than 10 or 20 years. In references [11–20] a great amount of information can be found on these sort of events.

Focusing on the technical aspect and consequently, on the learning factor, a conclusion that is easily reached is that, sadly, it is not a fundamental factor at the moment of designing these competitions. Anyhow, there are cases in which the technical aspect is highlighted. Interesting ideas that can be found are:

- Including an annex with pieces of advice on how to design and build the bridge (ASCE Seattle, USA, [14]). In the opinion of the authors of this document, this is a basic step on the direction of making the contest useful in the sense of Project Based Learning. The inclusion of these kind of documents has several advantages. The most obvious is that the students will not only have a basic reference to start their design, but also that they will notice that a more serious approach to the problem using mathematical models can help them a lot in their work. The absence of this document will probably lead the students to take the contest as only a playful and promotional activity, and, thus, miss the educational side of the event. The authors of this document have experience on a particular case of contest where no technical documentation is provided and, usually, the students think that they cannot perform the calculations or (even worse) they are of no use.
- Evaluating the best estimation on which will be the collapsing load of the structure (ASCE Seattle [14], Vermont Tech [18], Alberta [15]). This is a second step of most importance. The evaluation of the structures in most contest is made by simply loading it until failure. The problem with this is that this experiment is heavily conditioned by considerations not related to the quality of the design. Aspects such as craftsmanship, statistical deviation of the wood resistance or others can affect this result. If this estimation is given with calculations, one ensures that the student has at least tried to analyze the resistance in a technical way which can be evaluated.
- Asking for technical reports (ASCE L.A. [11], Vermont Tech [18]). This is an alternative to the precious evaluation. From a technical point of view, it is an even better approach, due to the fact that it involves the evaluation of these reports. The problem is that this evaluations are not quite popular among the students due to the fact that they can be considered subjective even if they are not. This usually discourages participants. The

advantage of the estimation exposed before is that it must somehow correlate with the failure load.

- Introducing changes in the conditions of the contest (ASCE L.A. [11]). This is of most importance, and should not only be done in the type of the loads, but also, and especially, in the boundary conditions, as it is done in the aforementioned reference. The importance of this is that this makes the contest more funny and also to avoid the reuse of calculations performed in previous editions, which leads to students which avoid the necessary analysis.
- Prizes to innovation (ASCE Virginia [13]). Although this is hardly a technical request, it increases the interest of the competition. Again, the subjective side of these kind of prizes can lead to problems.
- Taking as failure criteria a maximum value of bending deformation (50 mm). This very interesting idea can be found at Vermont Tech [18]. It is of most importance because the deformation comes from the structural analysis and not the resistance. This allows one to avoid the statistical effect of the wood resistance. In fact, this document is based on this idea, which allows a better correlation among the students analysis and the experimental results of the contest.

3. Including didactic calculations in contests

As has been mentioned before, except for a few examples, most bridge contests are centered on the resistance under loads of the structure, adding sometimes additional prizes, especially aesthetic ones. Consequently, the best result is obtained with an approximate knowledge of structural behavior and great manual skills. Although this makes the contest interesting and joyful, which is anyhow very important, it means leaving behind the possibility to include practical training in those degrees related to civil construction,. The objective of this article is to proof that it is possible, at a reduced cost, to take advantage of these contests in order to include this practical training. For this purpose, it is necessary for students to have the possibility to develop a mathematical model of the structure to build, with the required precision, but at the same time simple. The first problem we can generally find is the complexity to simulate the behavior of the glued joints and the wood used in these contests. To solve this problem, and as it is done in most of these contests, the solution is the organization to limit the type of wood to be used and, moreover, to supply it themselves. In the same manner (but we will see that is less important) it is interesting the organization to supply the glue too. The second problem comes from the lack of property information (elastic modulus, tensile strength etc.) of wood and glue. This problem is more complex than the previous one, and requires and effort and work by the organization. It is not only important they supply competitors with this information; it also requires certain rules that allow them to calculate the structure with enough simplicity. It is important to take into account that, in general, mathematical modeling of wood is much more complicated than the one of a metal like steel, and that the objective is not to do a very complex analysis, but a simple one that will allow students to apply basic mechanical, civil and construction engineering knowledge. The third and last problem is how to evaluate the quality of the mathematical model proposed by the competitors. Obviously, the loading process until failure of wooden structures is very attractive, but it is extremely difficult to accurately estimate the load at which one of these structures will break, due to the statistical variation of all the variables at play. Furthermore, the failure load can be heavily affected by a lot of phenomena which is not related to the quality of the design. For example, the craftsmanship of the builder can severely affect the final resistance and, even worse, the way the structure is loaded (which usually is not heavily controlled). Thus, it may seem much more interesting to pose deformation calculations for one or (better) a number of different load cases. The deformation is determined by the stiffness of the structure, and, thus, is not as influenced by craftsmanship or load history as resistance is. If these problems are faced in the correct way, the only requirement is to provide the students with some information on the available software to do their calculations. Here the student licenses available of different structure calculation or finite element software can be used if the contest is at University level or, otherwise, open source software. Handmade calculations should also be considered and encouraged, because they give a better idea of the theoretical knowledge of the student. Some of the available open-source tools that can be used to perform these calculations are exposed in Table 2, although it is also possible to some extent to obtain educational licenses of commercial software at a reasonable price. In any case, one must carefully check limitations that are usually applied to these kind of licenses such as reduced number of degrees of freedom in Finite Element Codes.

A final consideration can be made on the reports. Although reports are a necessary part of the learning, an effort must be made by the organization to keep them brief. Cumbersome reports discourage the participation and, even worse, lead to subjective evaluation. The authors have extensive experience

Table 2. Some of the open-source packages that can be useful for civil engineering projects

Name of Code	Type	Status
Code Aster (Salome-Meca)	Finite Element Analysis Package (Processor, Preprocessor and PostProcessor (ParaView), includes basic parametric CAD)	Fully Functional, both linear and non-linear capabilities
Elmer	Finite Element Analysis Package (Processor, Mesher and PostProcessor (ParaView))	Fully Functional, both linear and non-linear capabilities
Calculix	Finite Element Analysis Package (Processor, Mesher and PostProcessor)	Fully Functional, both linear and non-linear capabilities
FreeFem	Finite Element Analysis Package (solver)	Fully Functional, both linear and non-linear capabilities
FreeCad	Parametric CAD	Still under development, but quite usable
BRL-CAD	CAD	Fully Functional
Octave	Numerical Algebra Package	Fully Functional
Scilab	Numerical Algebra Package	Fully Functional
Libreoffice	Office Suite	Fully Functional
OpenOffice	Office Suite	Fully Functional
Latex	Word Processing software	Fully Functional

in these kind of contests and in some of them the participants decline to participate because the see over sized reports rewarded over other, technically better, but brief.

4. Procedure to obtain experimental data for participants

As has been mentioned previously, for a student to be able to develop a reasonable mathematical model, he needs a minimum amount of experimental data. The main problem that appears, is the resisting characterization of the glued joint. The most interesting option is to make this conditioning factor disappear. This can be due to the fact that, as is commonly known, it is easy to define a contact surface big enough to assure that failure will always occur on wood. Furthermore, is a requirement in the real engineering practice that glued joints should always fail at a higher load than the joined elements. Therefore, the first piece of information that can be given to participants is, for the given combination of wood and glue, under what conditions failure will always occur first on wood. It is especially interesting to pose these conditions as mandatory in the contest rules, so that the contestants that use mathematical models do not have disadvantages with respect to those who could try reducing the gluing surface (though, this can roughly suppose a great advantage). In the case of those contests where the wood is provided in the form of discrete elements such as popsicle sticks, the provided information can be provided in the form of a minimal glued length. In other cases, the organization must take into account the fact that, as it is known, stresses in a glued surface are not homogeneous and one cannot provide a minimal surface of the glued area without taking into account its shape. Another advantage of using the deformation as the goal of the analysis is that this information can be made irrelevant, but it is always interesting to ask the students to estimate the failure load.

In the first case, to determine the minimal glued length, even though it is possible to obtain an approximate value of the surface from the data supplied by the manufacturer, it is interesting to obtain through testing, experimental data of this parameter. This can be done with a tensile strength test machine, though, as expected, if we use an approximate value of this surface as starting point, it is easier to obtain a more adjusted value. At this point it is advisable to assign the minimum gluing surface with a certain margin, in order to avoid the possible errors produced by gluing problems (surfaces in bad state, dirt particles, etc.). It is also interesting for students to give information about peeling that will generally reduce the moment applicable on the joint.

Once the problem of the glued joint is removed, the process is quite clear. The first step is to obtain the values of the elastic modulus and ultimate strength of wood. This can easily be done by means of a tensile test analysis. The most important info to get is the young modulus, because it allows to perform deformation analysis without knowing the ultimate strength of the wood.

To make sure that the procedure proposed above can be used, an experimental test has been carried out. First of all, the aforementioned material characterization data has been obtained. After that a student has been chosen to test how does he manage to develop a finite element simulation of a bridge designed and built by him for the contest of the Escuela Superior de Ingeniería de Bilbao [19].

5. A practical example: wood characteristics determination

As it was mentioned before, the work of characterization of the material can be reduced to a number of tensile tests with the objective of determining the elastic and resistant characteristics of the wood, and also determining what surface of the popsicle sticks (in this case) it is necessary to glue in order to avoid adhesion failure when loaded. In order to characterize the wood used in the construction of the model, two instruments where used. On the one hand, bending, tensile and shear tests were carried out in an electromagnetic normalized test machine type IBERTEST ELIB with 100W of power (see Fig. 1 left). On the other hand, a hygrometer was used, type FMC Handheld Moisture Meter (Brookhuis) to measure the humidity of the different test pieces. This last equipment is not considered to be necessary in the real case scenario, as its influence, although not small, was not found to be of a major concern for the required precision. In any case, it is a good recommendation to perform the tests in the usual humidity conditions that appear in the region the contest is to be celebrated.

To carry out the tests, lines established in the UNE standards have been followed [UNE-EN 384:2010; UNE-EN 380; UNE-EN 14081-1; UNE-EN 338:2010]. Anyway, it has to be pointed out that the educational scope in which the proposal is developed, has led to introduce several simplifications. In any case, the number of pieces tested has always been of five or greater. The material under test has been wood of the ''populus canadiensis'' species, C–50 (conifers and poplar) [C.T.E., DB-SE-M, 2009)] under the form of popsicle sticks. The objectives of the first number of tests were to proof that the glued joints were more resistant than the wood itself. For this purpose, the test pieces that can be seen in the following image were used. They consist of 9 popsicle sticks stack with common white wood glue as depicted in Fig. 1 (right). Each joint represents 25% of the stick surface. The transverse section at the rupture zone (composed by 4 popsicle sticks) is of 80mm^2. The configuration used, does not only allow us to obtain elastic and resistant properties, but also allows us to verify the effectiveness of the glued joint. If this joint is correct, failure should always occur at the section composed of the least number of popsicle sticks. On the other hand, the distribution of the pallets complicates slightly the calculations, because stiffness changes along the test pieces. Disregarding the flexibility of the glued

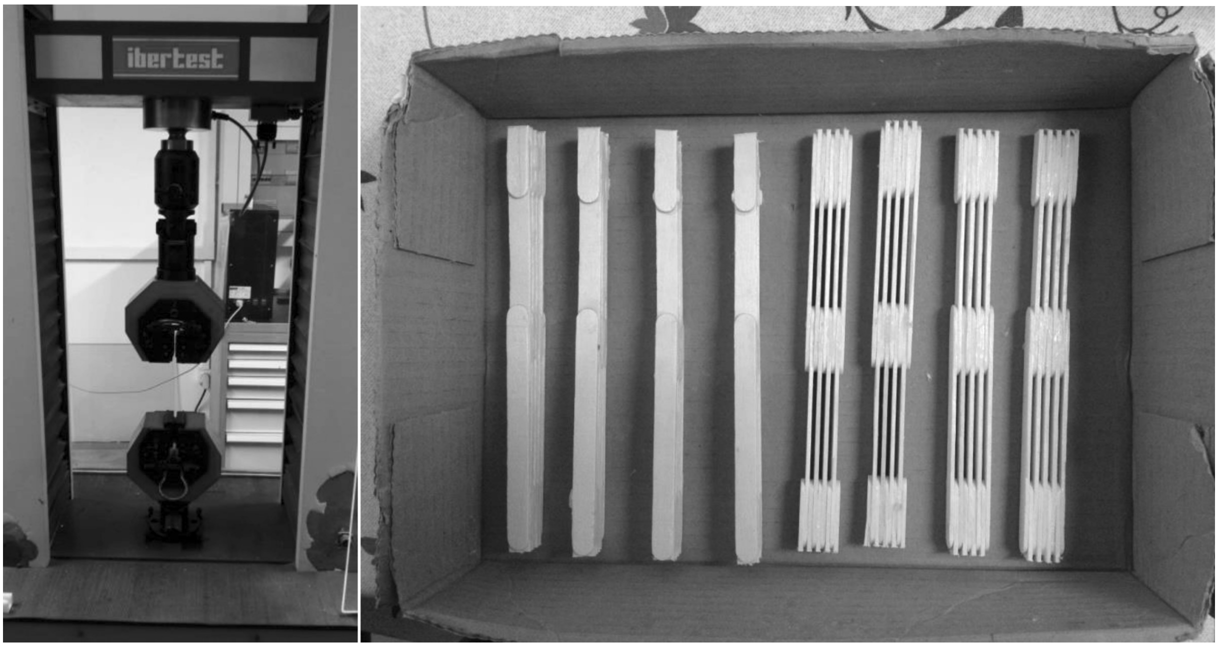

Fig. 1. Tensile test machine (left) and test specimens (right).

joints, and assuming that the flexibility per unit of length of each of the pallets, $^{1/K}$, is constant, the following equivalence can be posed:

$$\frac{I_1}{4k} + \frac{I_2}{9k} + \frac{I_3}{5k} = \frac{1}{K} \tag{1}$$

being ^{I_1} the length of the specimen composed of 4 pallets, ^{I_2} the length of the specimen composed of 9 pallets, ^{I_3} the length of the specimen composed of 5 pallets and K the total stiffness of the test piece. Once K is obtained, it can be stated that:

$$\frac{1}{k}\left(\frac{I_1}{4} + \frac{I_2}{9} + \frac{I_3}{5}\right) = \frac{1}{K} \tag{2}$$

thus:

$$k = K\left(\frac{I_1}{4} + \frac{I_2}{9} + \frac{I_3}{5}\right) \tag{3}$$

On the other hand, the flexibility per length unit can be written as:

$$1/k = 1/EA \rightarrow k = EA \tag{4}$$

And then we can free the elastic modulus, E:

$$E = \frac{k}{A} \tag{5}$$

The transversal section of each of the pallets is 20 mm^2. In the mentioned case, the minimum section corresponds to a number of four popsicle sticks, thus, the effective resistant section is 80 mm^2. Though it is true that the discontinuity among pallet-joints affects the resistance of the assembly, as it is not a very ductile material, on the one hand this fact only affects the tensile stress value, being negligible its effect on elastic properties. On the other hand, it is an effect that will appear on any model built with these types of elements, so the results will be useful.

The results obtained from testing the different pieces and that represent their general behavior, can be read in Table 3.

All of the test pieces under test broke in the wood section. This allows us to state that in any case that glued joints represent 25% of the wood length, not considering the peeling effect and for axial loads, the effect of glue can be disregarded in terms of resistance. As exposed before, one can also disregard its deformation because of the small thickness of the glued union. As expected, this is the most valuable conclusion obtained from the tensile tests carried out, because resistance characteristic data of wood can be obtained from other resources, for example from UNE-EN 338, though it is always better to have values obtained from testing the material the dealer has provided. We can see in the results obtained that elongation at the moment of failure is clearly excessive, which can be attributed to a slippage problem at the fixing points of the test pieces, meaning these tests cannot be used to estimate the elastic properties of the material. To correct this effect, a new number of tests were carried out, this time, on individual popsicle sticks individually in order to obtain the Young's modulus, value that was fixed in 1220 MPa. In order to obtain an adequate value with the assembled popsicle sticks that were presented initially, a special tool that guaranteed that slippage would not occur would have to be developed.

Taking all of this into account, one can conclude that, in order to get the required experimental data to be provided to the contenders, about 3 days of work and a simple traction test machine is all that is needed. An important remark has to be done here about the low friction coefficient among the wood and the grippers on the used machine. As exposed before, this can be solved by a means of adequate tooling.

Table 3. Experimental Results obtained in tensile tests

Specimen	Maximum Load (kN)	Max. Elongation (mm)	Tensile Strength (Mpa)
1	6.2	28.02	34.44
2	5.96	26.95	33.11
3	7.13	25.95	39.61
4	7.37	27.95	40.94
5	7.5	29.336	41.67
Averages	6.83	27.64	37.96

6. An applied example to the calculation of a bridge

To proof that a student, having the required information and a minimum piece of advice, is capable of obtaining results good enough to be compared to those obtained in the analysis of a mathematical model developed with the data acquired up to now, a student that participated in the 2015 popsicle stick bridge contest of the Escuela Superior de Ingeniería de Bilbao, sponsored by BBK, was chosen and asked to do a theoretical and experimental analysis of the bridge he had designed and built for the aforementioned contest. The bridge is shown in Fig. 2 (left).

As one can see in Fig. 2 (left), the considered bridge is too complex for a student to be hand-analyzed, so the student was advised to do so by means of a finite element software. Even though there are other software more oriented to civil engineering, the software PTC Creo was chosen, because due to its licenses oriented to Universities, it

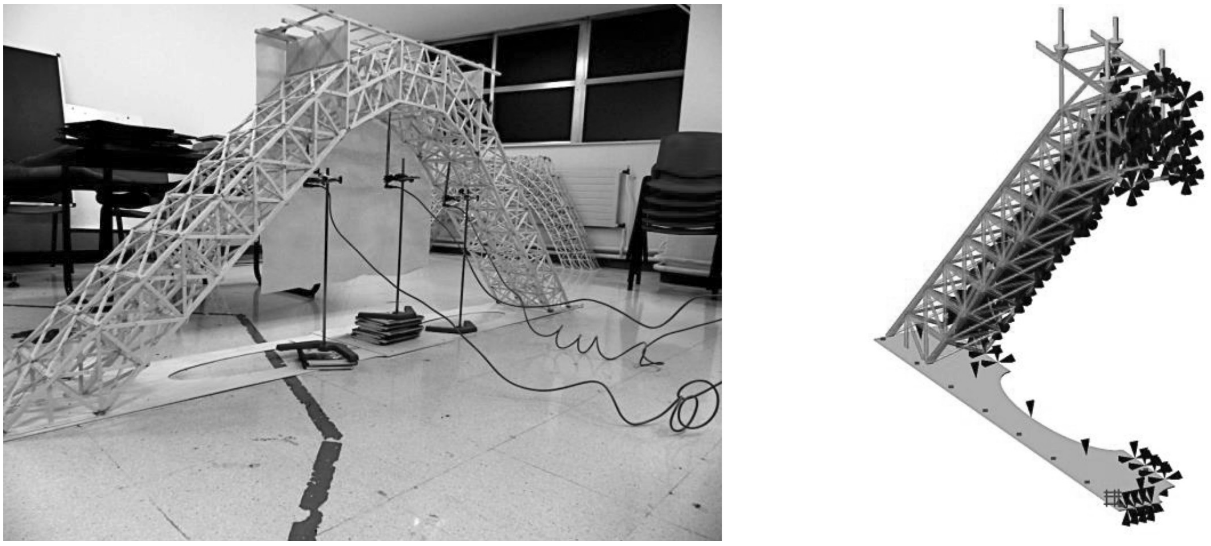

Fig. 2. Popsicle Bridge (left) and Finite Element Model developed by the student (right).

was the cheapest option. The use of an open source option can also be considered. For the experimental test, the bridge was loaded with 105 kg of weight. The measurements were done by means of a data acquisition system with 128 channels built by Hottinger Baldwin Messtechnik and controlled by a MGC Plus Catman Easy 3.1 software, including two displacement sensors that were shared out symmetrically along the span of the bridge and that can be seen in the previous image. The load was applied progressively until a maximum displacement of 0.75 mm was obtained. This displacement was chosen because it was near the middle of the total load required for the failure. It is important to point out that one of the facts proved in this experiment is that the stiffness of the board that serves as support for the bridge can have great effect on the displacement of the bridge, which leads to think that it should be taken into account by the organization in the contest regulations.

In Fig. 2 (right) the final finite element model developed by the student can be seen. As it is a structure with double symmetry, the student decided to model only a quarter of the bridge, introducing the boundary conditions corresponding to symmetry and reducing this way the preprocessing and computational cost.

The loads were modeled taking into account the loading process of the bridge, using tiles. Thus, the loads were applied on the nodes that can be seen in the image above, and taking into account once more the necessary symmetry conditions. The analysis developed was a static analysis and the results obtained can be seen in Fig. 3.

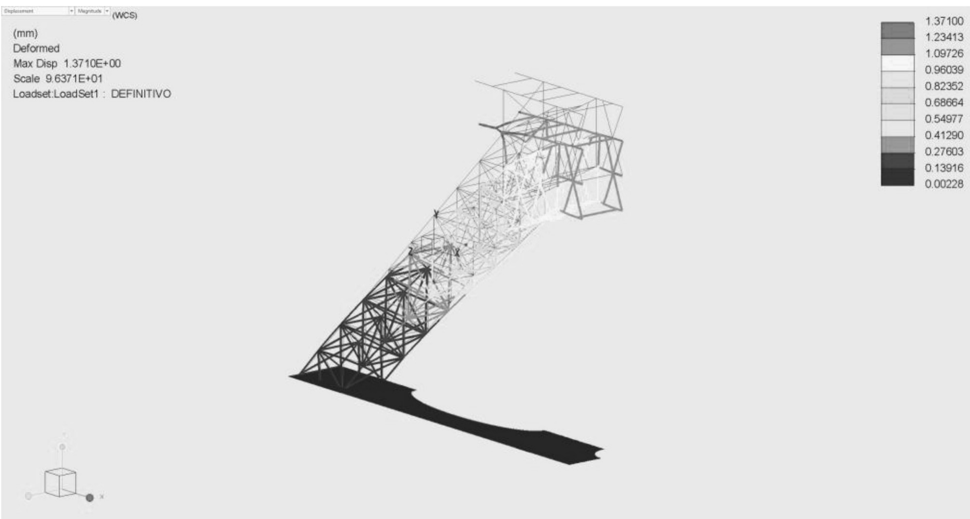

Fig. 3. Deformation obtained in the Finite Element model.

The displacement obtained in the node measured during the experimental testing by means of the finite element model was of 0.9 mm, whereas experimentally a displacement of 0.75 mm was obtained. It can be considered a very good result if we consider the statistical variability of the behavior of wood.

The initial analysis that the student performed before this final model had a lot of room for improvement. In the first model the use of solid elements lead to an overwhelming cost of computation. Furthermore, the size of the used elements was too small, which lead to an overestimation of the stiffness of the bridge. After the tutors advice, the use of beam elements reduced the cost while improving on the result. This analysis lead to the same results that the one exposed, but it was considered that taking advantage of the symmetry was something interesting for the student, which lead to the final model presented. This model had a better computational cost than the previous one. This allows one to see that there are plenty of aspects that can be useful to objectively evaluate the student work. In any case, a good correlation of the real and computed deformation should be the most relevant value to be evaluated, because there is no doubt on their objectiveness. The evaluation these other more technical aspects of the analysis could be introduced as an additional prize.

7. Conclusions

Popsicle bridge contests and other wood structure contests may seem more like a playful activity than a practical one, especially compared to other competitions at university level such as Formula Student, Air Cargo Challenge, Motostudent or others. However, it can be proposed as a complementary activity applied to building in the education of civil or construction engineering students. Analyzing it in such manner, their main advantage is the reduced cost they have, being in most cases zero compared to other contests like the ones previously mentioned. In fact, the only drawback that one can find on these kind of competitions is the lack of multidisciplinary and probably the difficulty of the inclusion of work in groups. Nonetheless, in order to make the most of these types of contests a previous work by the organization is required, to supply the students with enough data to develop a mathematical model of the designed structure, with a minimum degree of precision. Under these conditions, a minimum characterization of the material behavior together with enough data can be obtained by means of a tensile test machine. This is due to the fact that, under certain conditions, two important simplifications can be assumed. The first of the two is that the glue is strong enough to guarantee that failure of the structure will never occur due to it. The second is that if this glue is applied properly, the layer of glue is so thin, that it's flexibility is negligible compared to the flexibility of wood. Taking this into account, the student can develop a mathematical model with any commercial software for structure calculation available at university or otherwise, using open source software like Salome-Meca, Elmer etc.

At the moment of judging the validity of the calculation in a hypothetical contest, it is advisable to introduce objective criteria of calculation precision. In order to achieve this it would be better to use displacement measurements well below failure loads because at the moment the structure is going to collapse factors difficult to control appear, such as local stability of the structure. As one of the most attractive things for viewers in these type of contests is to load the structure until failure, it seems illogical to suppress this aspect. Thus, a good option would be to consider the mathematical modeling of the bridge as another extra category inside the same contest.

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