End of degree project

Ingeniería en tecnologías industriales

Analysis and design of a prototype to raise awareness about education in bridge schools in India

REPORT

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BRIEFING

Dirt, no access to electricity nor to clean tap water, dangerous materials, are some of the characteristics of the environments where unfortunately many indian kids grow up. In the face of the incredibly large ratio of poverty that strikes the country, many families live in unbelievable harsh conditions, mostly being slums located in the surroundings of cities. Even if parents work extremely hard to be able to pursue a better life for their family, in many cases they have to leave their children unattended during long day hours in such hazardous circumstances. Luckily, more and more, enterprises and NGOs are putting their efforts towards granting all kids access to education.

Last February, I had the opportunity to travel to Bangalore to participate in a social innovation camp, which intended to improve education conditions in bridge schools. These infrastructures built by Selco foundation, are portable units that are installed in slums for children to have the opportunity to learn, but also to access a solid meal and hygiene conditions. Seeing that in many cases the fear of leaving their kids in an unknown place to be taken care by exterior teachers, scared parents away taking away with them the opportunity of the youngest ones. As a result, a method to raise awareness about education had to be found so as to familiarize the community of its importance, and that's when this project was born. After getting to know the context and the nature of the problem, a modular board was designed to tackle this issue. Some research confirms that personalized spaces increases the sense of achievement and belonging as well as the recognition and value of external people. Knowing this, the idea was to build a board, that could be used both in interior and exterior environments, to showcase students' work all along the week. The object has a system that allows hanging the work but there is also a foldable blackboard that serves as a teaching surface as well as an informational panel. There is also a cover that stops the content from getting damaged, and thanks to its lightness and simple method of use it can be rolled-up for easy transportation and storage.

Nevertheless, after a first prototype design many technical aspects needed to be worked on. For this reason, this project contains a material research that finds out that the most suitable components are bamboo, PVC and a combination of cellulose and polyethylene to form the bars, the cover and the main surface respectively. Moreover, to prove that the object met the stiffness and resistance requirements, a stress study is carried out which determines the key dimensions the board needs, to be able to sustain the most extreme situation in which a kid could hang himself from the bar. Finally, since many things had changed from the initial model, the design needed to be optimized and new measurements have been established to better adapt the object to the beneficiaries and the environments conditions. Safety parameters, simple local manufacture, low cost, lightness and minimization of the environmental impact are the main points of study that project entails. All in all, this report contains the all the information regarding this technical thorough research, which has met all the set objectives. The final result leaves us with a practical object that could be implemented in a near future to make communities realize the importance of education.

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1. Preface

India, while having one of the fastest growing economies, still has a 68.8% of its population suffering from poverty, the most vulnerable members of society being children. Most of them live in the countryside, but rapid urbanization is pushing them increasingly to the metropolitan areas of big cities leading to the growth of informal settlements and slums. There, not only hygienic conditions are inexistent, but drinkable water and electricity are also very scarce. However, despite the effort of NGOs and foundations to grant them access to school in these very remote environments, the nature of their surroundings makes providing quality education an on-going challenge.

In order to ameliorate the impact and the quality of education during the child's growth, working on improving the emotional comfort of the children at school is essential. Through some research it was discovered that having a personalized space has a direct link with the enhancement of self-esteem in children and therefore this project was created. The device developed is a modular and movable board with the main purpose of showcasing the students' work.

With a deep understanding of the context and the previous development and validation of a low fidelity prototype on the field a technical study of materials and stress resistance will be executed to achieve an optimized final design of the prototype. A viability study will be carried out to ensure the results achieved can be further implemented in the context they were designed for. This approach will be conducted thanks to the expertise from the team and the external sources provided.

2. Introduction

2.1. Objectives

The main objective of the project is to design a prototype that improves academic comfort in bridge schools by enhancing students' self-esteem.

Moreover the secondary objectives are the following:

1. Analyse the main educational necessities in bridge schools
2. Define the problematic and adapt it to the work environment
3. Study the technical requirements in terms of stress and materials
4. Design the optimal prototype that suits the restrictions
5. Evaluate the viability and impact the project will have

2.2. Scope

The project is conceived as an extension of the initial proposal elaborated with two other students in India as part of a social impact camp. Even if the team still works together to raise awareness about the proposal and encourage youngsters to carry out such kind of tasks, this project is understood as a study from a more technical point of view of the already existing prototype. Not only will the previous on-site analysis done will be clarified, but also a study of the potential materials that could be used, the stress boundaries they should work in and the resulting optimized design will be reviewed. In order to verify the results are trustworthy in terms of following the applicable law and the required security limitations, a validation study will be executed.

However the project has some limitations, it will not consider a very thorough analysis of the economical or legal point of view due to its complexity related to the constant modifications and the upcoming global situation. This means that the costs will be revised as well as the basic security requirements however the project doesn't intend to elaborate an implementation plan at the field. Moreover, any other technical study that is not stress or design related will be left out of the scope. Consequently, the project will only cover the stages of definition, analysis and validation, without considering the implementation process itself, due to the lack of resources, expertise and time.

The research is intended to improve the existing design and be of help to develop future models of the prototype in India. More specifically, the idea is to supply them to the new bridge schools Selco Foundation is putting in to place all around the country. As a result, this would have a straight impact on the children and teacher improving the school dynamics. However it would also influence indirectly the whole community including the parents of students.

3. Field work

3.1. Context

Nowadays, according to a study from *The Times of India* [1] there are 2000 slums around the city of Bangalore even if the government only recognizes 597 of them, causing an estimate of 25%-35% of Indians live in such urban slums. This proves how these overcrowded hazardous living environments that suffer from a lot of social complexities are under recognized. The poor living conditions affect the health of the people living there, but children are especially vulnerable. In many cases, parents take off each day for long work days leaving their kids alone in such insecure environments. Thanks to the work of local NGOs, schooling not only grants them the opportunity to be supervised and educated, but also nourishes them and provides them with hygiene and health.

Designing successful solutions that handle social issues is not something that can be done overnight. Embracing all the cultural, social and economical difficulties that take place in the context for which the project is developed is very challenging but at the same time essential to be able to carry out a human centered design approach. This method enables to build a better understanding of the problematic and co-create the product together with the final users by constantly testing and improving the prototype thanks to their feedback. In my case, this was made possible thanks to INSSINC (India Switzerland Social Innovation Camp), an initiative organized by EPFL (École Polytechnique Fédérale de Lausanne), which is a two weeks-long program that immerses students in Bangalore to tackle social innovation challenges on field. Participants work in interdisciplinary teams, mixing engineering, design and social sciences to address local problem statements together with SELCO Foundation and Swissnex India.

As a result, it was essential to immerse ourselves in the local culture and understand the context we were working in, such as getting to know the communities and the condition these children lived in. Our projects took place in two slums located at Electronic City and Whitefield, which are quarters of the Indian city of Bangalore. The living conditions are very harsh but luckily children have access to bridge schools, which are temporary learning spaces granting them basic education in the hope to integrate them into government schools. These bridge schools often have only one teacher, limited space and a large number of students from different ages (2-8 years old).

Three teams were made out of the 10 participants, diving them into three main working areas: lowering the teacher’s workload, tackling the learning differences between age groups and improving the learning comfort. Together with Iscia Vos, a physical engineer and Romain Talou, a designer, I as an industrial engineer, was a member of the third group.

Since our team's focus was on learning comfort issues, after observing the challenging conditions of life, we decided to tackle an aspect that might not always be of first importance, but that actually had a big impact in such an environment, which is the emotional comfort of students. It has particularly been seen that children's self-esteem is directly influenced by their own pride, their sense of accomplishment, their sense of ownership and the encouragement of their relatives. In the same way, having a personalized environment affects our sense of achievement and belonging, our pride and the recognition and value of our work. There is a clear link between these two concepts, thus displaying children's work would have a positive impact on their personal development boosting their self-esteem [2][3]. As a result from these findings, Roll'up was conceived as a movable modular board used to showcase students' schoolwork.

3.2. Process and methodology

The first stage to improving the learning comfort of children in the bridge schools in India was taking one step backwards to be able to build an understanding of the issue's context, the users and their behaviours. Observing and discussing with multiple beneficiaries on the field helped comprehend their needs which weren't always necessarily stated or easily recognized. The focus was not only put on analyzing the school's infrastructure and furniture but also the interaction of the users in the space. Working in two different schools made using multiple methods and data sources necessary to discover people-inspired insights to support the design approach. In the first place, images and sketches [I] were used to document the site in a visual way and have a better comprehension of the dimensions and use of space. Furthermore, a What-How-When-Why matrix [II] helped obtain much more detailed descriptions of the observations emphasizing on the different activities that took place (eating, playing, learning...) and the use of several pieces of furniture (storage units, walls, ceiling...). Finally, interviews were also a method to engage with the users in a way to facilitate the expression of their needs and ideas.

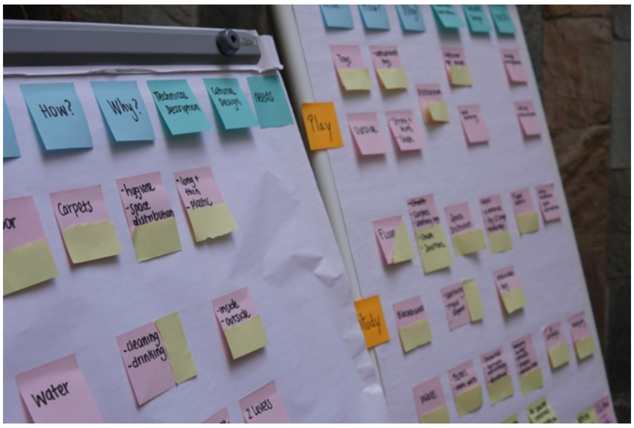


Figure 1 What-How-Why matrix analysis

Figure 2 Discussion with beneficiaries and experts on-site

Making sense out of the collected data was essential to discover unmet needs that hadn't been directly observed on the field but that could open new design opportunities. However it required generating as many ideas as possible while leveraging from experts to find one single right solution, thus the scope was narrowed down to the need for a different surface to access school material. It had been observed that their blackboards were always lying around the floor and the teacher stuck newspaper on the walls to be able to put up the drawings and posters on top because it was the only way of holding them up. Moreover, they also had space issues because the classroom's available surface was limited and the number of students was quite large and varied in range of ages. Consequently, the resulting idea was a movable wall that could be used to showcase students' work and allow the teacher to extend the learning space onto a new surface. Therefore there were two different activities that involved the concept we wanted to create: teaching and showcasing.

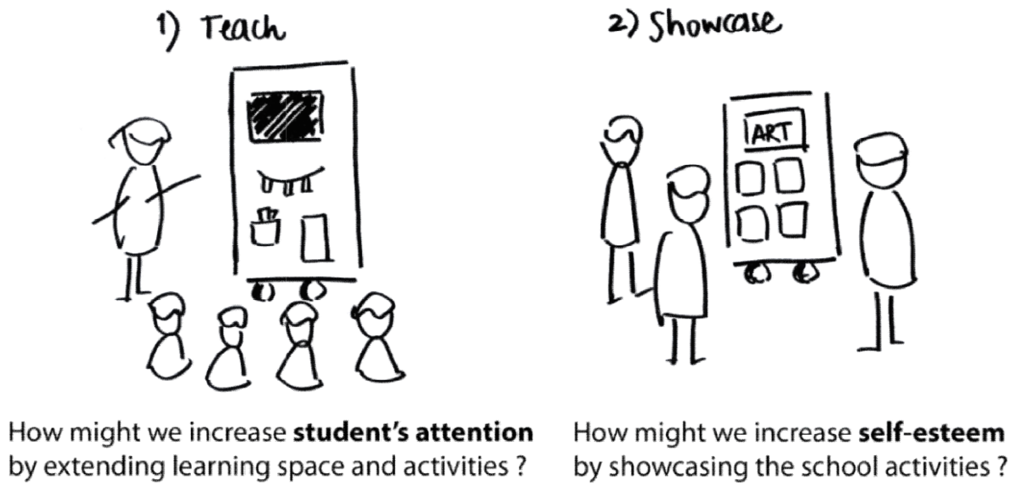


Figure 3 The two different possible problematics

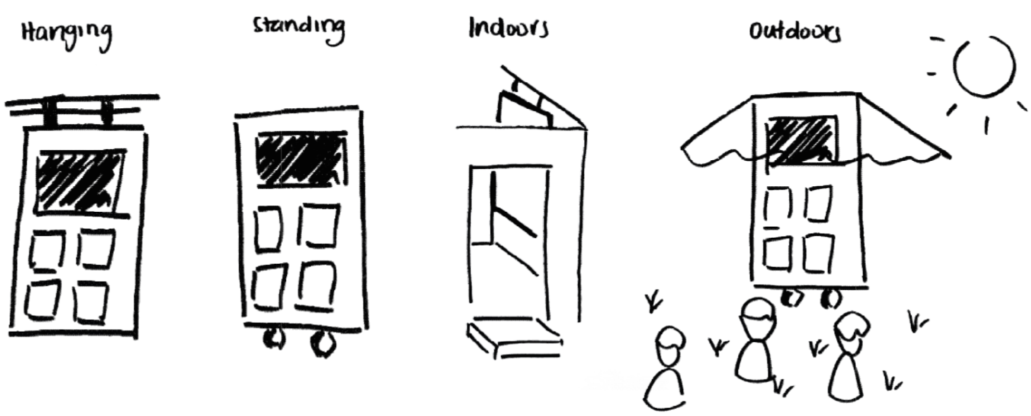


Figure 4 Several sketches that illustrate the possible modularity of the object

Taking the proposition to the environment it was being designed for was necessary to give value to it and test its desirability and feasibility. At this point we started to work on building the first prototype which consisted of a small scale movable wall created with very low resources, such as cardboard. By merging the users' feedback with the observations we realized focusing on showcasing the students' work was the most suitable direction to work towards. As a result, we modified the proposition on the field to adapt it to the new framework, eliminating the wheels that were of no use because of the landscape, choosing lighter materials to make it a more manageable surface and taking note of the measurements and space needs. To test this we hung some work the children had done on a newspaper board over the main door and it was then when we truly realized the reaction it caused in them. Therefore the problem statement that arose was: “How might we increase self-esteem by showcasing the school activities?”

Figure 5 Small scale initial prototype

Figure 6 Field test of second prototype

At this point we had 2 possible new propositions show in Figure 7. The first one used the already existing ceiling infrastructure to create a hanging system that would work through a pulley system, and the second one resembled more to the initial idea but it was a hanging portable board. Despite the fact that both ideas could be carried out independently, time was a very big restriction and we decided to choose the second options which didn’t depend or modify the actual school architecture and could be moved into different spaces very easily.

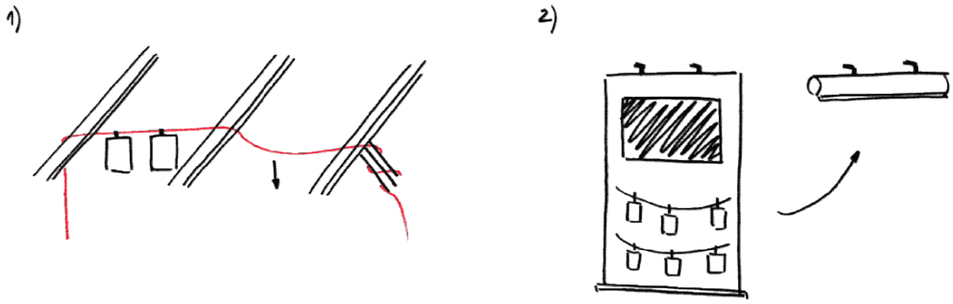


Figure 7 Two new possible propositions

We were now facing a new challenge, how to manufacture the prototype in an unknown city using limited resources? The solution was to scout the streets being resourceful and creative to find local artisans to work with, such as carpenters and tailors. This was necessary to prove that it was possible to find the needed materials and means to be able to produce the board in India in the future.

Figure 8 Local artisans manufacturing the wooden dowels

Figure 10 Local tailor sewing the main tissue layer

Figure 9 Testing different methods of assembling the prototype

Figure 11 Finishing the final details and checking with experts

For a solution to have an impact in real world conditions it's not enough to be acceptable, but also accessible and adopted by society. The aim was to test some technical aspects of use such as mobility, simplicity and modularity, but also to observe the behaviour of users. On the one hand the goal was to observe the kids' enthusiasm while hanging up their work and their pride when showing it to their classmates and parents. On the other hand, also realizing how the teacher made the object hers and created a whole activity around it. Finally it was key to have the chance to talk with some parents to know how satisfied they were with the work of their children and wanted to continue seeing their progress. Consequently, even if there were some details that still had to be modified, the validation of the proposal was achieved. The objective now was to develop the future plan to decide how the project would move on because even if we were leaving India, there was still much that could be done.

Figure 12 Teacher creating a class activity using the prototype

Figure 14 Students' amazement while seeing their own work hung up

Figure 13 Teacher carrying the board from the outside to inside

Figure 15 Community and parents observing the showcased work

3.3. Initial prototype design

The initial prototype design elaborated in India is mainly composed of three layers. The main one is a tissue layer with a blackboard and strings to hang the students' work from both sides. Then, there are another two layers of transparent plastic, one on each side of the tissue layer, to protect the work from weather conditions, from dust and from kids ripping it off because of excitement. All three of them are held together on one end by a wooden dowel, which has a handle to carry it around and some ribbons to roll it up. Finally on the bottom part of the tissue layer there is another wooden dowel to create weight and attach the plastic layers so as to provide stability to the board.

Thanks to the simple composition, the prototype is light and can be effortlessly rolled up to be easily stored and transported. Additionally, both sides of the tissue layer can be used to hang up projects and the blackboard can be folded up in different sizes which make it modular for the teacher to use as much teaching space as she needs. Moreover, the prototype was also designed to be easily hooked inside and outside the infrastructure of all bridge schools in India since its size is adapted to their particular architecture. However, since the access to materials was limited, the dimensions of the object were very approximate and could be readjusted.

Lastly, in terms of manufacture, it requires few and simple materials which are easily assembled with the help of local artisans. In the first place, some wood manufacturers created the wooden dowels by cutting the pieces to length and doing the correspondent grooves. Then, with the help of a tailor, the ribbons were sawn all the way around the tissue and the plastic layers, as well as the blackboard which was attached at the upper part of the tissue. After this, the only remaining thing to do was to thread all the layers, including the ribbon for the handle through the upper bar and fix everything in place with some special glue for fabric. Finally, the bottom bar was also fixed in place and the eyelets and velcro pieces were manually saw in.

Figure 16 Rolled-up version of the prototype

Figure 17 Hung-up version of the prototype

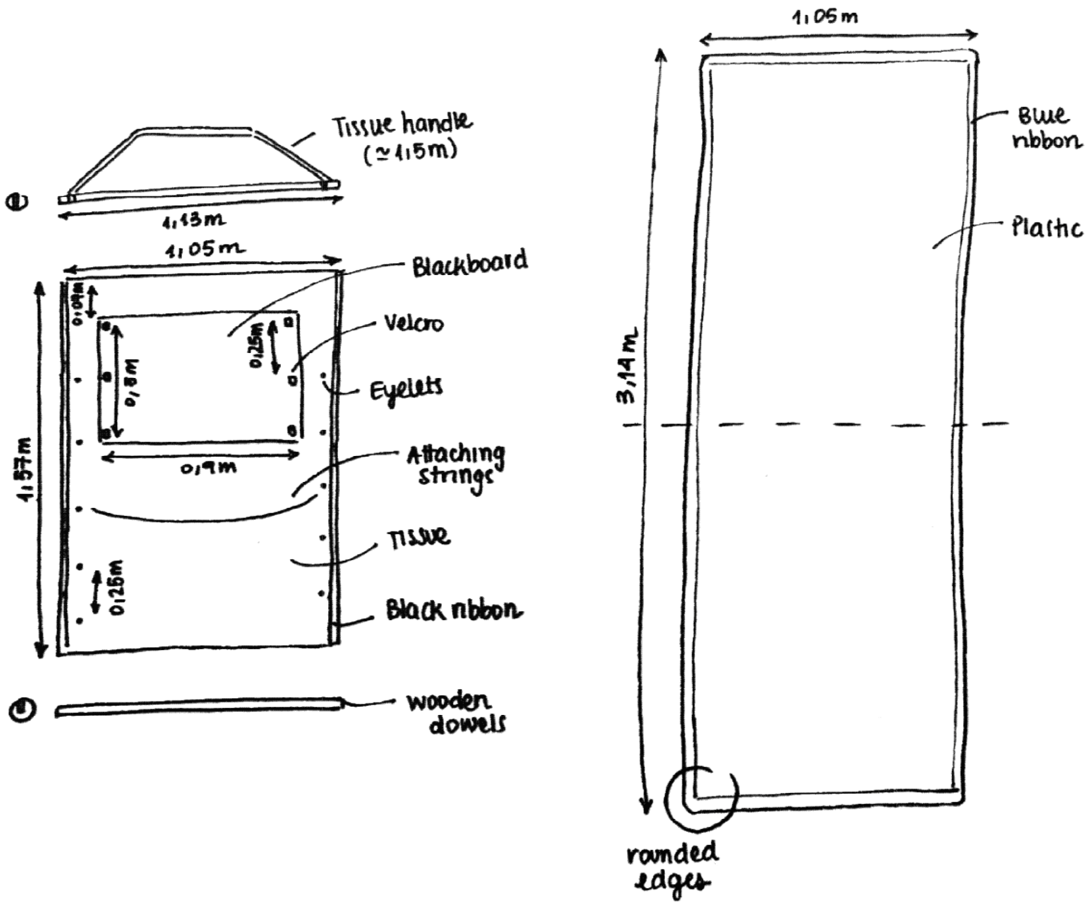


Figure 18 Sketch of dimensions of the first prototype[1]

[1] The blueprints of the model can be found in section [III] of the appendix

3.4. Initial prototype validation

The validation process took place during the last field visit, mainly to observe the short term results. On the one hand the technical aspects of the prototype, to see whether the teacher could easily use it, were checked. Regarding students, it was important to verify the height of the stings and their ability to hang their work by themselves. On the other hand, testing the immediate impact of the prototype was essential, even if we were conscious that our presence created a non-negligible bias. The clearest observation was the pride of children while hanging their work, which reformed their normal school experience, as well as seamlessly infusing an exercise that allowed them to use their own agency to showcase to their class and community something they developed. However it was particularly surprising how the teacher appropriated the object and created a whole activity around it together with the children. Finally, some parents also curiously approached the board and showed great interest in knowing more about their child's progress.

Nevertheless this project didn't end here. Even if the long term benefits could not be studied on-site, the prototype still needs improvements in terms of material selection, manufacturing techniques and design aspects. Luckily not only were we able to leave one board in each school but also maintained contact with the teachers, from whom we have already started to receive feedback. Our strong relationship with the experts from Selco Foundation in Bangalore also allows to have a direct update of the insights and keep collaborating with local manufacturers.

Consequently, there are three main groups that would profit from the long term impacts. Firstly, students would experience a personal development that would increase their sense of accomplishment, their sense of ownership and their self-esteem. Furthermore, parents' acceptance towards the school and the teacher's work should also improve which would be tested by measuring their interest in school activities through a questionnaire later. And lastly, these two main groups would help raise awareness about the importance of education amongst the surrounding communities to encourage more slums to have bridge schools and turn them into community centers.

4. Technical study

After having completed a full two weeks of research and initial designing, there are still several aspects that have to be studied much more thoroughly from a technical point of view. In the first place, the materials used to build the prototype were not always optimal since there weren't many resources nor time available at the time. Another feature that should be examined is the joint between the three main parts seeing that there were some problems when testing it on-site. This is also linked with the manufacture process as well as the environmental impact it can have. And finally, the design might be affected by this parameters thus it should be modified accordingly.

4.1. Study conditions

Before starting to search for the most suitable materials and the necessities of the object, it is essential to determine the context it is going to be put under. In this case, these conditions are two: the actions from the children that make use of the board and the environmental conditions in which the object is used.

4.1.1. Estimation of the maximum load

To obtain the nominal load (F_{nom}) that the object has to be able to sustain, we have to take into consideration the maximum weight that can be hung from it. Normally the board would be used to showcase school work, although being used in a school environment with quite young children, there is always the possibility that a kid plays with it by pulling the board towards him or even trying to hang himself from it. As a result, to ensure the object can hold capably enough all the conditions it can be subjected to, the F_{nom} will be calculated based on the average weight of a child.

To start off, some criteria regarding the data have to be highlighted: the size of the samples used are in all cases roughly the same, the data remains equal along the years, the data used is collected from Indian children to have a narrower and more precise population of study.

On the one hand, since the data of the average weight is available by age groups, the mean for each gender has to be calculated. However, only the ages from 5 to 10 years old, being normally the maximum age of bridge school students, will be taken into consideration:

- Average weight of a boy (5-10 years old) = 24,38kg
- Average weight of a girl (5-10 years old) = 22,40kg

Moreover, given the percentage of male population is larger than the female population, in order to calculate the average weight, the data has to be scaled accordingly. Knowing that 52,11% of the underage population are men and

47,89% are women the mean for the distribution of the weight of an Indian kid is 23,43kg.

On the other hand, to figure out the standard deviation, it is essential to know the following formulas:

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n}(x_j - \bar{x})^2}{N}} \qquad \sigma = \sqrt{\frac{\sum_{i=1}^{n}\sigma_i^2}{n}} \qquad [\text{Eq. } 1, 2]$$

Where each parameter stands for:

- σ ≡ standard deviation
- x̄ ≡ mean

Consequently, the standard deviations for the male and female groups are 4,39 and 3,98 respectively which leads to a total standard deviation of 4,19.

All in all, once the mean and the standard deviation are calculated the remaining step is to draw a normal distribution with both parameters and find the value that leaves a probability of 5% to its right, in which case the superior bar will only fail in those cases.

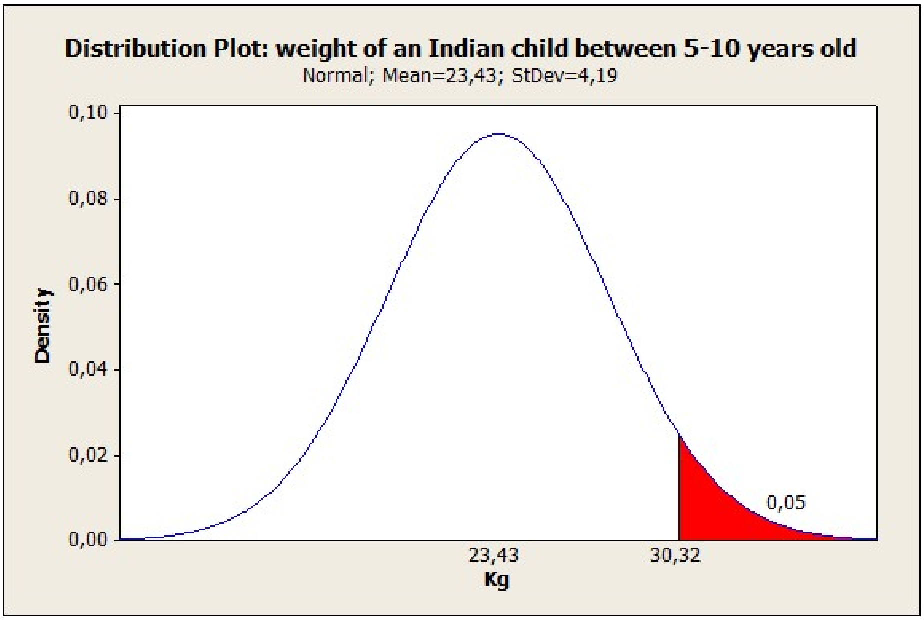


Figure 19 Distribution plot of average weight of Indian child (ages 5-10 years)

Therefore it can be concluded that the average weight that must be used so as to obtain the nominal load is 30,32 kg. Furthermore, if it is multiplied by the gravity (9,81 m/s^2) to then obtain F_{nom}= 297,44 N.

4.1.2. Environmental conditions

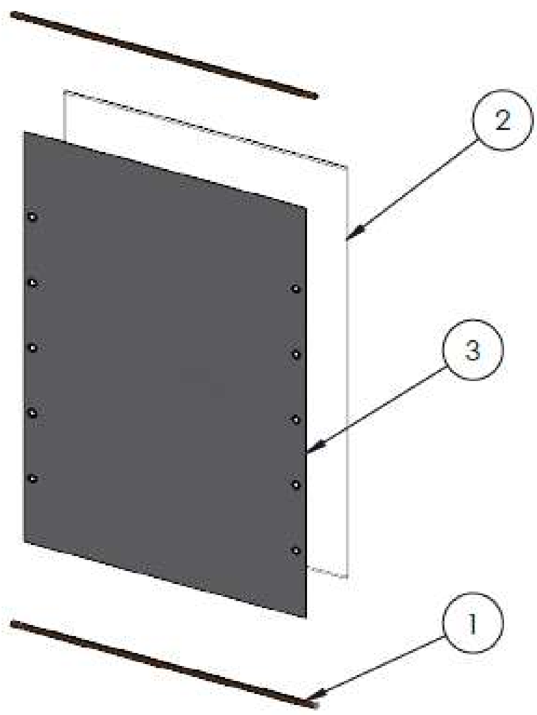
India has 3 main climate seasons throughout the year: summer, monsoon and winter time. During the summer period, which normally lasts from March until June, the average temperature is in the range of 33-42^{o}C but can rise until maximum values of 47-50^{o}C. Monsoon season, known as the time of rain from June to September, can strike Indians with a mean of 230mm of rain per month that can go up to a maximum of 395mm per month. Finally the colder weather comes in early December until middle March, having sunny days (around 25^{o}C) and cooler nights (around 10^{o}C).

Most of the times, bridge schools are built in very rural areas, and since these infrastructures are quite simple and small, the students and scholar equipment are in constant contact with the harsh exterior conditions. It is therefore vital to take these parameters into consideration, mainly when choosing the materials since the objective is to obtain a product that doesn’t cost much but lasts in time.

4.2. Materials research

4.2.1. Requirements

When studying the different materials that intervene in the prototype we can clearly distinguish three main parts: the top and bottom bars, the main showcasing surface and the protection cover. Even if all three of them make up the same object, they are all exposed to different conditions and therefore need to sustain distinct mechanical and atmospheric requirements, although there are some general needs that have in common all parts of the model.



REFERENCE	DENOMINATION	QUANTITIES
1	SUPERIOR AND INFERIOR BARS	2
2	PROTECTION COVER	1
3	SHOWCASING SURFACE	1

Figure 20 Designation of the three main parts of the object

Table 1 Technical requirements of the object

Mechanical requirements	Atmospheric requirements	Additional requirements
✓ Rigid structure ✓ High resistance	✓ Resistance to water ✓ Resistance to UV light ✓ Resistance to corrosion or degradation ✓ Maintain its properties in range of service temperatures	✓ Economical ✓ Colour ✓ Lightness ✓ Flexibility to store ✓ Easy purchase ✓ Easy manufacture ✓ Not toxic or allergenic

Taking into consideration the aforementioned criteria, it is also important to emphasize that even if all of them would work under the same conditions, each part has a specific function and therefore some requirements have a bigger weight in some cases than others.

The upper and lower bars are the main structure of the object and therefore the ones in charge of holding up the model and where most of the weight falls on. As a result, for this part, the mechanical requirements have to be studied exhaustively to ensure the prototype won't fall apart. The needs in this case are:

- ✓ A rigid material to ensure that the initial and final geometric configuration of the bars do not differ excessively, meaning that the Young's Modulus has to be maximized.

- ✓ High resistance, so as to be able to sustain an elevated load, specifically the weight of a child (F_{nom}) [4.1.1]. Hence, the yield strength needs to be risen.

In the case of the protection cover, as its name states, the main function it carries out is maintaining the board and its content safe, mainly when being outside. Consequently the atmospheric requirements should definitely be taken into consideration, although some additional characteristics are also quite important when choosing the material for the cover:

- ✓ A waterproof material that can withstand large quantities of rainfall, as well as a UV light resistant material that is able to maintain its properties on very sunny days. Seen that the countries temperatures can rise until considerably high values, it would also be important to consider a material that stays solid and maintains its properties in the temperature range of 0-60^{o}C.

- ✓ Resistance to degradation and corrosion is also important, taking into consideration the object will suffer from harsh conditions and it is meant to have a long life.
- ✓ Since it is intended to be a protection cover, the material has to be transparent to be able to see through it the content that is being showcased at the moment.
- ✓ Space limitations are quite frequent in bridge schools, thus the prototype was meant to be easily rolled to take up as less space possible. To be able to do so, the material should be flexible to allow being stored in reduced spaces.

Furthermore, the main body of the object is the middle layer surface that allows hanging the work to be showcased. This space requires some specific qualities regarding environmental conditions but also some mechanical restrictions. Even if the bars are the points that can suffer the most because there is the possible scenario of a kid hanging himself from them, the main body should be able to sustain a pull from a child. The necessities are the following:

- ✓ Having a minimum limit of resistance and rigidness to protect it from breaking down.
- ✓ Having a colour that allows projecting clearly the showcased art, but at the same time dark enough to avoid getting very dirty quickly when touched by kids.
- ✓ In reference to the aforementioned point, it has to be a material that can be washed easily and with basic hygiene products like soap and water without getting damaged.
- ✓ As well as the protection cover, it has to withstand some weather conditions such as UV light and high temperatures when being in exterior spaces.
- ✓ Being a flexible is also essential to be able to roll it up and transport and store it easily.

Finally there are some basic criteria that all three main materials should enclose which are:

- ✓ Low cost materials in order to obtain an affordable object to be able to provide as many as possible.
- ✓ Materials must be of easy purchase and manufacture since the production is intended to be carried out in India by local workers.
- ✓ Minimized mass to save material and ensure that the board can be easily transported from inside to outside spaces without requiring much time or energy.
- ✓ Since the object is intended to be used in schools, it must not be toxic or allergenic as it could put students in danger.

4.2.2. Materials selection

4.2.2.1. Part 1: Superior and inferior bars

The main function of the upper and lower bars is to give structure to the object while having a minimum mass.

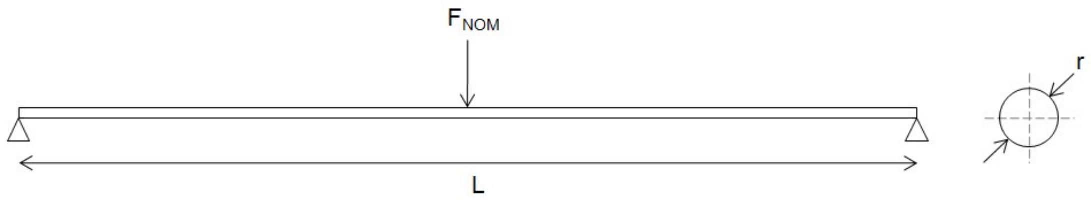


Figure 21 Geometry and requirements of the bar

Once analyzed the requirement, the imposed restrictions are the specified length of the bar and sustaining a bending stress > S*. The equation that takes the mechanical conditions into consideration is the following:

$$S^* = \frac{C \cdot E \cdot I}{L^3} = \frac{C \cdot E \cdot A^2}{4 \cdot \pi \cdot L^3} \quad [Eq. 3]$$

Since the objective is to minimize the mass, the equation used is:

$$m = A \cdot L \cdot \rho \quad [Eq. 4]$$

The free variables are the material selected and the section of bar therefore, using the following equation of the mass, the obtained benefit index is M_1.

$$m = \left(\frac{S^* \cdot 4 \cdot \pi \cdot L^3}{C \cdot E}\right)^{1/2} \cdot L \cdot \rho = \left(\frac{S^* \cdot 4 \cdot \pi \cdot L^5}{C}\right)^{1/2} \cdot \left(\frac{\rho}{E^{1/2}}\right)$$

$$M_1 = \frac{\rho}{E^{1/2}}$$

Where the parameters stand for:

- m ≡ mass
- A ≡ area
- L ≡ length
- ρ ≡ Density
- E ≡ Young's Modulus
- I ≡ momentum of mass inertia
- C ≡ constant

The aim is to minimize the benefit index M obtained to ensure a light material. Therefore, the procedure will be to determine the slope of the index individually and study which materials fulfil the criteria. The initial material selection is made using the Ashby diagram E-ρ (with the help of *CES Edupack* program), the slope considered is 2 and the interest zone is the superior one, since the benefit index has to be minimized.

$$M_1 = \frac{\rho}{E^{1/2}}; \quad \log E = 2\log\rho - 2\log M_1$$

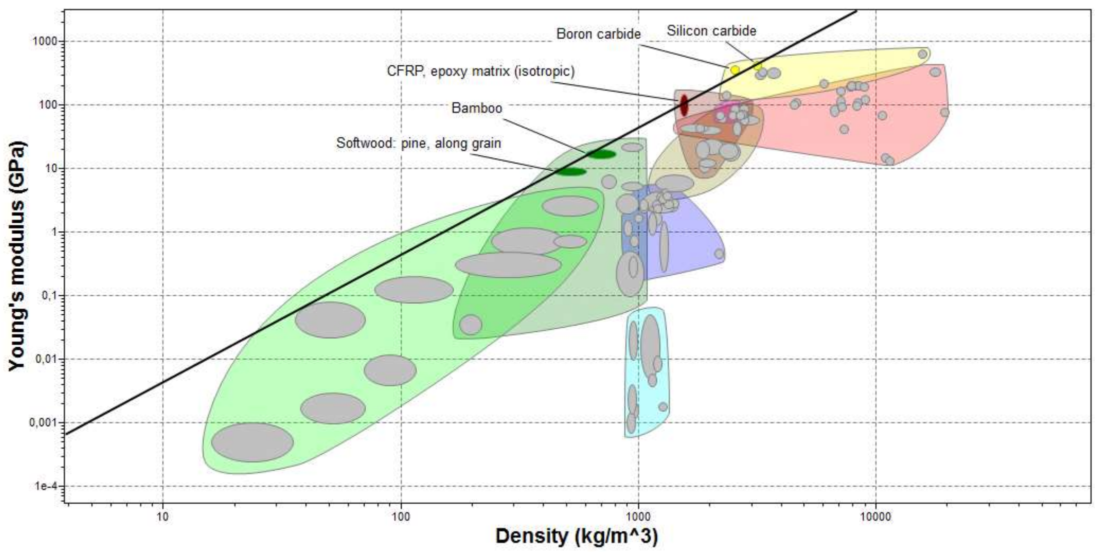


Figure 22 Ashby diagram of the young modulus vs density

As seen in the diagram, the first selection of materials that fit the needs mentioned above and its respective properties are the following ones: boron carbide (technical ceramic), CFRP expoxy matrix (composite), bamboo (natural material), softwood (natural material) and silicon carbide (technical ceramic). However, the most suitable material is still not found thus a second benefit index regarding the minimization of the cost is defined according to the following expression:

$$\mathrm{Price} = \mathrm{ppk} \cdot \mathrm{m} = \left(\frac{\mathrm{S}^{*} \cdot 4 \cdot \pi \cdot \mathrm{L}^{5}}{\mathrm{C}}\right)^{1/2} \cdot \left(\frac{\rho}{\mathrm{E}^{1/2}}\right) \cdot \mathrm{ppk} \quad [\mathrm{Eq.}\,5]$$

Where the parameters stand for:

- ppk ≡ price per kilogram
- m ≡ mass

Knowing this, the index can be expressed as:

$$\mathrm{M}_2 = \frac{\rho \cdot \mathrm{ppk}}{\mathrm{E}^{1/2}}; \quad \log \mathrm{E} = 2\log(\rho \cdot \mathrm{ppk}) - 2\log \mathrm{M}_2$$

In this case, the slope is still 2 and the goal aims to minimize the index as much as possible, looking at the superior interest area of the Ashby diagram ρ·ppk - E.

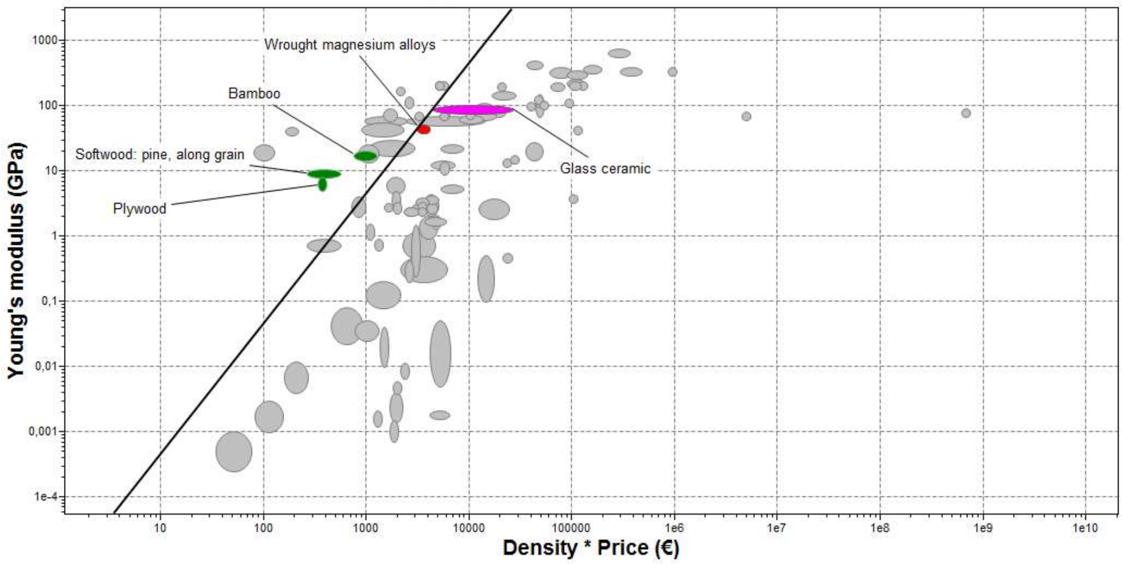


Figure 23 Ashby diagram of the density·price per kilogram vs young modulus

In this case, it can now be concluded that the five top materials are: softwood, plywood, bamboo, wrought magnesium alloys and glass ceramic. The only two candidates that are in both selections are from the natural materials family and are either bamboo or softwood (typical along grain). Since both materials are very similar, to be able to make the final decision we must go back to the starting point, the context. Seen that the object is aimed at the Indian culture, and that it will be manufactured by locals, bamboo would be a very good choice since it's a particularly fast growing resource in Southern Asia used mainly for construction purposes due to its high resistance. More strictly, we can also observe in the graphs that bamboo has slightly better mechanical properties than wood and a very similar price. All in all, both materials could be a good choice although in this case bamboo is recommended.

Bamboo can be thought of as a hollow tube, exceptionally strong and light, that can be harvested after a year due to its fast growth (reaching a height of 15m and a diameter of 0,3m). Thanks to its hard surface and very easy machinability, it is usually used for construction purposed because it adapts very well to rural and industrial conditions. Nowadays, there is also the possibility to obtain solid bars of bamboo if they have relatively small diameters. The only characteristic that we must pay more attention to is the fact that it is not an homogeneous material and since it is natural, the properties may vary a bit from one piece to another, but in general they are the following ones:

Table 2 Properties of bamboo[2]

Density (kg/m^3)	Young modulus (GPa)	Shear modulus (MPa)	Yield strength (MPa)	Tensile Strength (MPa)	Compressive strength (MPa)	Poisson's ratio
699,5	17,5	490	39,95	239,5	79,95	0,32

4.2.2.2. Part 2: Protection cover

Regarding the protection cover, the selection was done by introducing all the characteristics as restrictions in a filter to find out which group of materials was the most suitable one.

In the first place, it is essential to determine the maximum and minimum range of service temperatures to ensure the material will conserve its properties at all moment. Therefore, according to the previous study [4.2.1] about climate conditions in India, the established interval of temperatures is 0-60°C.

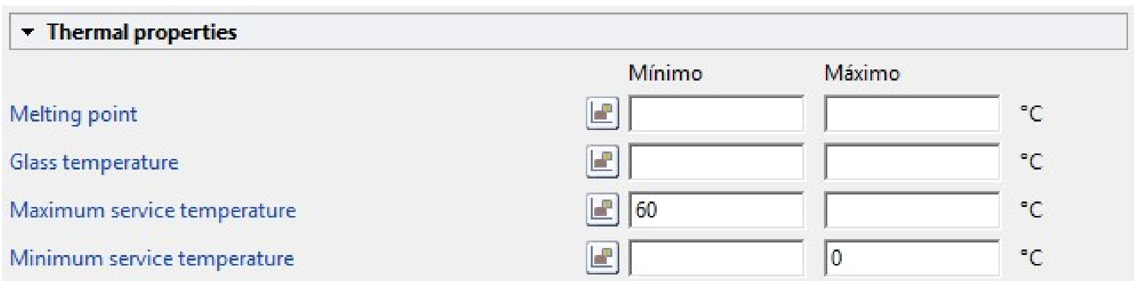


Figure 24 Thermal properties established in *CES Edupack* for part 2

[2] Obtained from the material database of *CES Edupack*

In the second place, another requirement is to have flexible materials that allow being folded up to ease storage and transportation situations. Therefore, an upper boundary for the young modulus is established to ensure the chosen material is not too rigid.

Figure 25 Mechanical properties established in *CES Edupack* for part 2

Moreover, guaranteeing that the cover is water resistant is crucial to carry out its main purpose of protection, both in rural and industrial environments depending on the location of the bridge school the object belongs to. In addition, as established before with the temperature range, the cover can be exposed to solar radiation, thus it must be able to outlast it too.

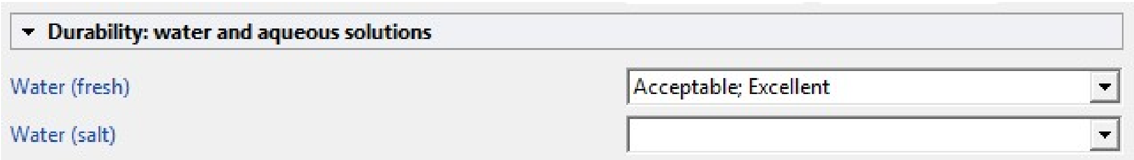


Figure 26 Durability: water conditions established in *CES Edupack* for part 2

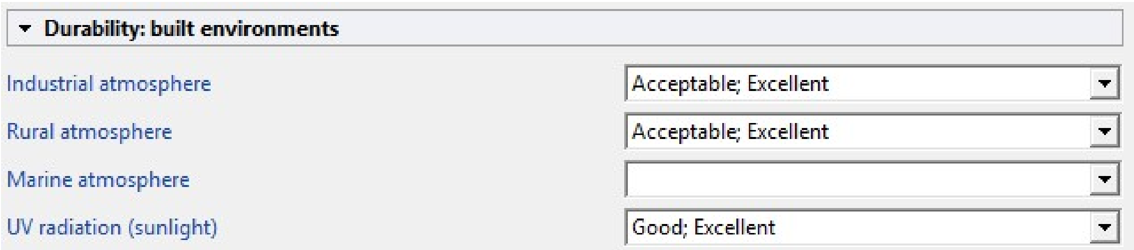


Figure 27 Durability:built environments established in *CES Edupack* for part 2

Since the intention of the cover is to secure the content of the board, but at the same time allowing it to be showcased, it is vital that the chosen material is see-through.

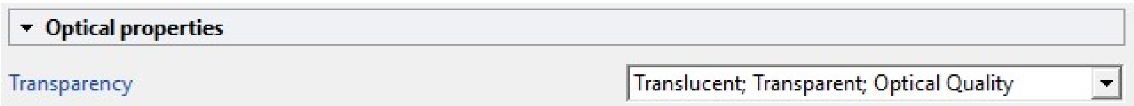


Figure 28 Optical properties established in *CES Edupack* for part 2

Furthermore, to narrow down the selection even more, some extra conditions were added such as the capacity of manufacturing the material and its weight are crucial so as to be able to handle it and store it easily. Nevertheless, the price must be considerably low to afford the production of a large amount of units. And finally, but not less important, since it is an object that remains constantly in contact with human beings, it is very important that it isn't a danger for their health.

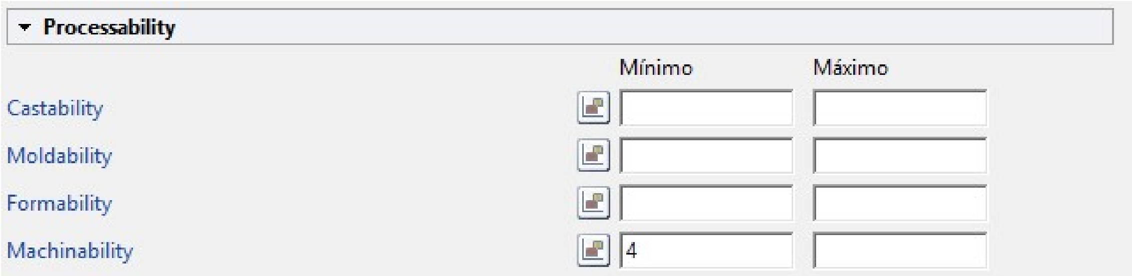


Figure 29 Processability filter established in *CES Edupack* for part 2

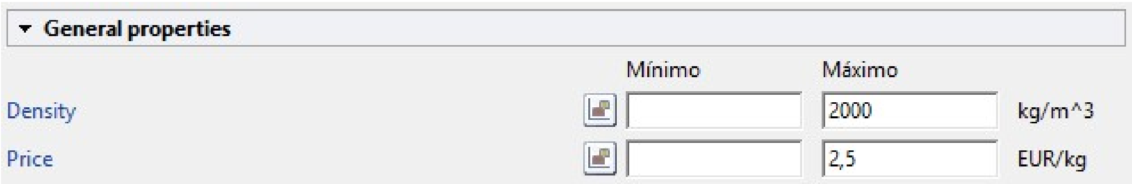


Figure 30 General properties established in *CES Edupack* for part 2

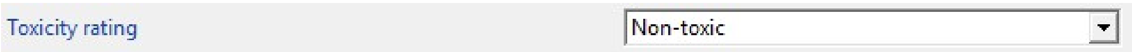


Figure 31 Safety filter established in *CES Edupack* for part 2

After applying all this restrictions, the remaining materials are all from the polymers family: Polyethylene terephthalate (PET), Polyvinylchloride (PVC) and Starch-based thermoplastics (TPS). All of them are very capable candidates, although after doing some extra research, it has been found that each one has different uses normally, and in the case we are studying PVC would be the most suitable one.

PVC vinyl is one of the cheapest and most commonly used polymers due to its varied properties. In its pure state as a thermoplastic, it is rigid and not very tough, but with very cheap procedures and the incorporation of other components it can turn into either a flexible rubber-like material just by adding plasticizers or a stiff and strong solid used in building panels integrating glass fibres. Consequently, PVC is available as a film and in many other ways due to its capacity to join with other elements and has very good protection properties against atmospheric gases.

4.2.2.3. Part 3: Showcasing surface

To find out the ideal material for the third part is harder since there are fewer restrictions imposed and as a result several materials fit the requirements. However, a similar study than in the previous part [4.2.2.2] has been carried out to classify which are the remaining candidates.

In this case the temperatures imposed were the same range, although other restrictions were eliminated such as the optical requirements, or were given less importance.

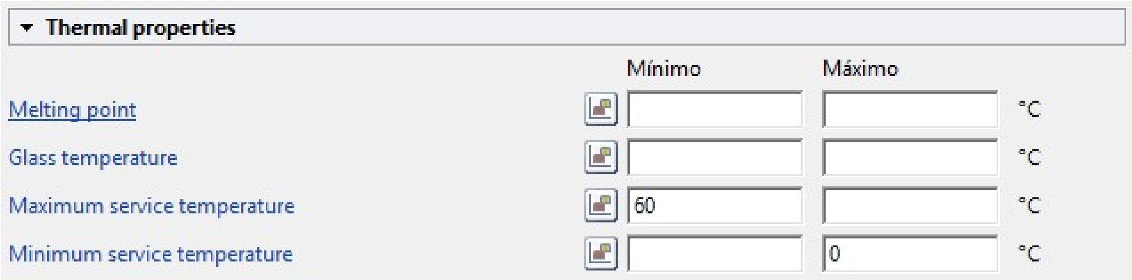


Figure 32 Thermal properties established in *CES Edupack* for part 3

However some minimal mechanical conditions have been imposed because even if the superior and inferior bars are the ones that give structure to the object and would suffer the most in extreme cases, the main surface should also hold up some minimum stress in less severe cases. As a result, a minimum value of yield strength and young modulus is established to guarantee some resistance, although an upper boundary is also added in the case of the young modulus to avoid having a very rigid material since one of the requirements is flexibility to be able to store it easily.

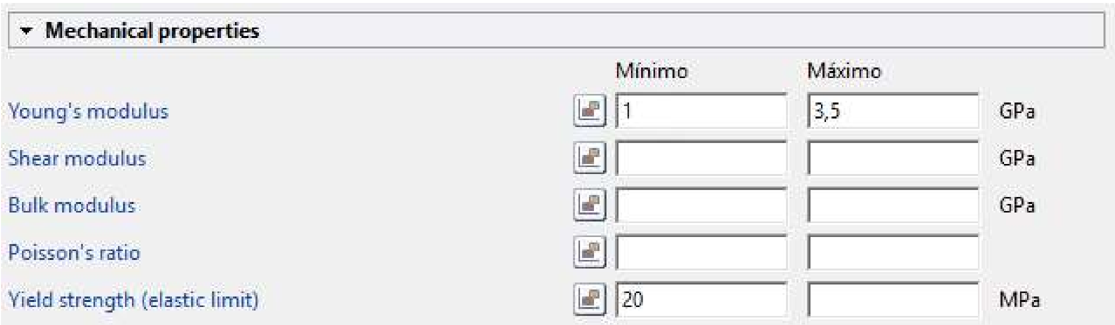


Figure 33 Mechanical properties established in *CES Edupack* for part 3

In the following cases, the same properties have been studied but without being so strict since the layer responsible for protection is the cover studied before. Therefore the main board should ensure some durability but it will be mainly guaranteed through the protection given by part 2.

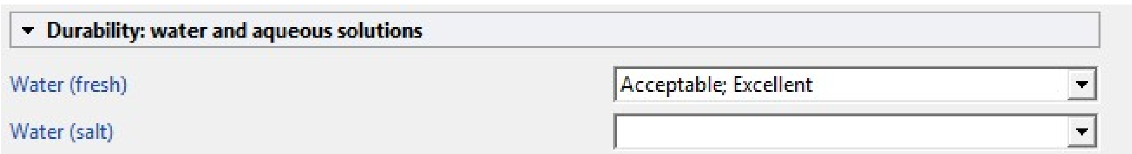


Figure 34 Durability: water conditions established in *CES Edupack* for part 3

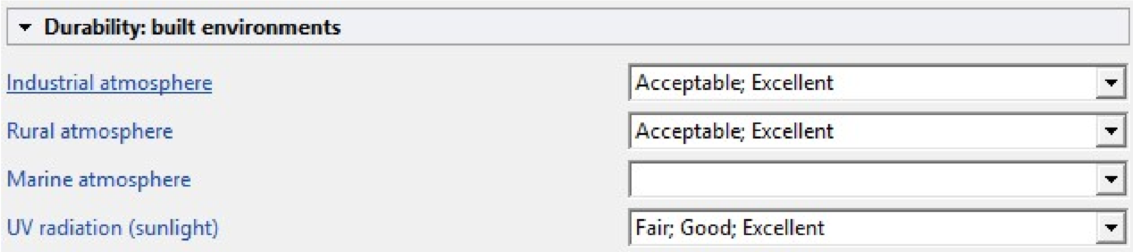


Figure 35 Durability:built environments established in *CES Edupack* for part 3

Finally, a low mass, an economical price, simple production and safety remain as vital conditions imposed to finish the selection of suitable materials.

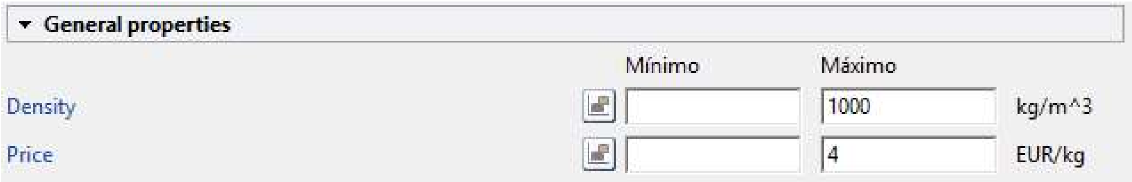


Figure 36 General properties established in *CES Edupack* for part 3

Figure 37 Processability filter established in *CES Edupack* for part 3

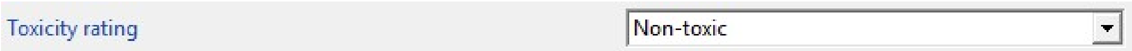


Figure 38 Safety filter established in *CES Edupack* for part 3

Cellulose polymers (CA), Ionomer (I) and Polyethylene (PE) are now the alternatives which also belong to the polymers family, but are used in different contexts than the previous ones. In this case, making a decision is harder since all three need to be combined with other components to obtain the final showcasing surface. Cellulose is known to be used in the textile industry to produce fabrics, as well as in domestic and industrial coverings. Ionomers are commonly found in packaging and sports equipment and PE is employed for insulation purposes, food packaging and disposable clothing. For this reason, the election of this final material could be either cellulose or PE, although a more thorough study combining these materials with other elements should be done to obtain a product with better and wider properties. However, in this case to simplify the study, the surface will be considered as a composition of 50% CE and 50% PE, given that the cellulose gives it the textile properties and the polyethylene the insulation component.

4.3. Stress study

After knowing what kind of materials are going to be used in each part, it is important to do some calculations understanding the possible load that the object can undergo to determine the geometrical requirements it has to fulfil to be able to sustain them without breaking down. As said before, the area that gives structure and resistance to the model are the bars, in particular the top one. Therefore, in the following points a study will be done to analyse the load and the consequent stress distribution, the section of the bar, the possible deformations and the behaviour of the junction between the bar and the rest of the object.

4.3.1. Stress Distribution

The purpose of this project is to reflect the reality in the most accurate way possible, in order to obtain results that have the less error possible. However, given the complexity of the real model, it is necessary to simplify it, so the outcome is the closest to the authentic one. There are some limitations that need to be considered: the restrictions that come with the construction process, because of the manufacture machinery and local situation, and the conditions implied by the chosen material.

Idealizations are a very useful simplification source when analyzing very tangled problems, often even essential to be able to find a solution. Nevertheless, the more simplifications it has, the more it differs from real results. This is why the idealizations made are the following:

- The material used is considered homogenous, although in reality there are no materials with such characteristics in its entirety.
- The material used remains in the elastic zone under stress to ensure linearity. If the elastic limit were to be exceeded, there would be a ductile failure –which means working in the plastic zone– were the stresses are not proportional to the strain. Therefore, the stress analysis would be much more complex.
- The possible interior stresses obtained in the piece because of the cutting process are not taken into account.
- The own weight of the bar is neglected as it would be insignificant compared to the forces that will be applied to the piece.
- The contact zones and the load application are considered punctual, as if they were not the calculations would turn out to be extremely complex, and restrain both the vertical and horizontal displacements.

The starting point for the design of the upper bar, is establishing the direction of the longitudinal axis in a two-dimensional space (XY). Using a completely straight bar would not only ease the production, but also gives very good results when working with anisotropic materials made out of fibers. Moreover, it is known that any vertices, understood as points where there is a harsh change of direction, can be critical points where internal stresses tend to build up; hence they should be minimized as much as possible.

As a result, the forces that are applied and the resulting stress distribution are the following:

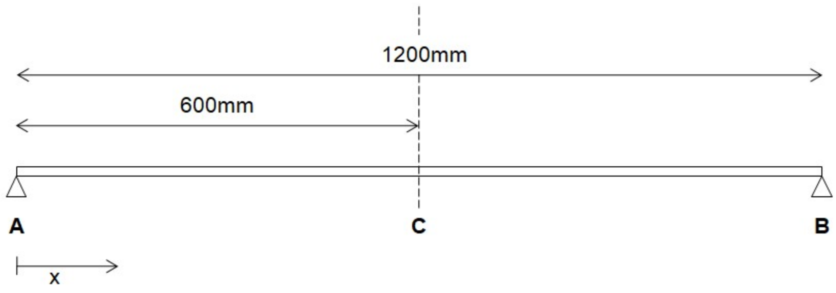


Figure 39 Diagram of measurements and sections of the bar[3]

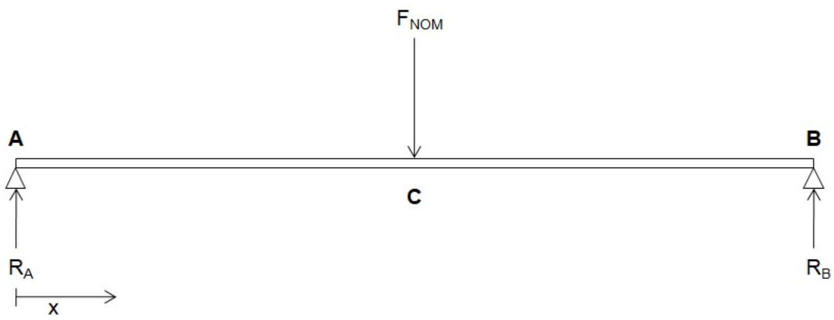


Figure 40 Diagram of forces applied on the bar

[3] All measurements are specified and justified in chapter [4.4.1]

$$\sum F = 0 \quad [Eq.6]$$

$$R_A + R_B - F_{NOM} = 0$$

$$\sum M(A) = 0 \quad [Eq.7]$$

$$-F_{NOM} \cdot 600 + R_B \cdot 1200 = 0$$

$$F_{NOM} = 297{,}44N \quad R_A = 148{,}72N \quad R_B = 148{,}72N$$

Table 3 Forces and momentum distribution by sections along x axis

Section	N_X	T_Y	M_Z
AC	-	R_A	$R_A \cdot x$
CB	-	$R_A - F_{NOM}$	$R_A \cdot x - F_{NOM} \cdot (x - 600)$

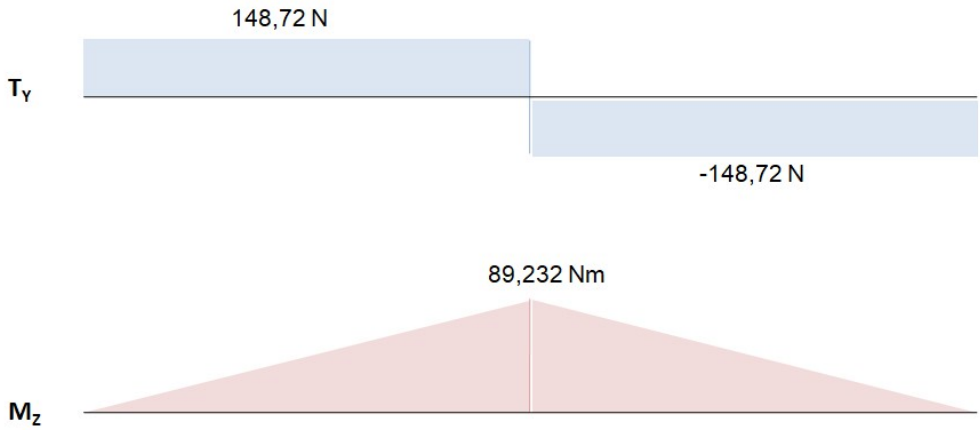


Figure 41 Diagram of stress and momentum distribution

The calculations and results obtained confirm that the most efficient way of joining points A and B is with a straight bar, since the material needed is less than in any other disposition, which makes the weight and consequently the price lower too. Furthermore, the load distribution is only vertical which means that the momentum only depends of x. As a result, the critical point of the bar would be B since it's the area where the momentum is higher.

4.3.2. Dimensioning of the section

To be able to decide the measurements of the sections it is important to justify the shape it is going to have. On the one hand, the objective is to have a rigid and resistant piece, which translates to being able to sustain a large load but at the same time suffering minimum deformations. To achieve this, the mass moment of inertia perpendicular to the section should be maximized. On the other hand, optimizing the amount of material used is also a goal to obtain a light bar. Finally, the election has to be done having in mind the possible restrictions that come with the manufacturing process.

Some possible options could be T and double T sections because they give very good results and their production is standardized, therefore it wouldn't give many problems. However it must not be forgotten that the bar is just a part of a whole object and therefore this piece needs to work well together with the other two parts. For the same reason, and because of the complexity it can entail, variable sections are not considered.

The most simple, but at the same time quite efficient section, is the circular one because it has a geometrical performance of ≈¼ and it is completely symmetrical, hence the tensions are equally distributed. Another advantage due to its simplicity is that producing it won't bring many complications and as a result the errors made won't be many, neither the waste of material. Nevertheless it is important to have in mind that the bar will have a good performance only when the fibers are located in the direction of the longitudinal axis, perpendicular to the load. Moreover, since it is a natural material, a security coefficient should be applied so as to cover the appearance of knots or any other intrinsic imperfection.

Furthermore, a very similar option could be the tubular shape, which could in the first place seem a better option because it would reduce the mass. Despite the fact that its geometrical performance is ≈½, since there is only momentum on the z axis (simple bending: M_z+T_y) and it's not the case of deflected bending (M_z+M_y), the goal is to maximize the mass moment of inertia (I_z). Therefore, knowing that I_z for a circular section can be calculated as in [Eq.8], it will be maximum when the interior diameter *d* is minimum, hence when the circumference is solid rather than hollow.

$$I_z = \frac{\pi \cdot (D^4 - d^4)}{4} \quad [Eq.8]$$

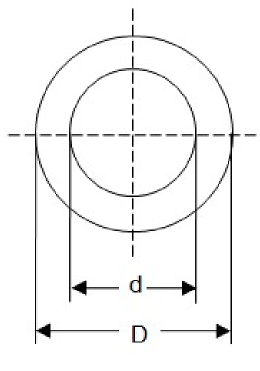


Figure 42 Parameters of the tubular section

Once having decided the shape and knowing that the critical section is C, it is essential to determine the dimensions that are capable of sustaining the service load. Being aware of the stress the section undergoes, it can be seen that the normal stress is way bigger in value than the shear stress, thus the calculations will be done regarding the points where the normal stress is more noticeable (points 1 and 2). Nevertheless, the points that suffer the maximum shear stress (points 3 and 4) will be then verified to ensure they are also within the boundaries.

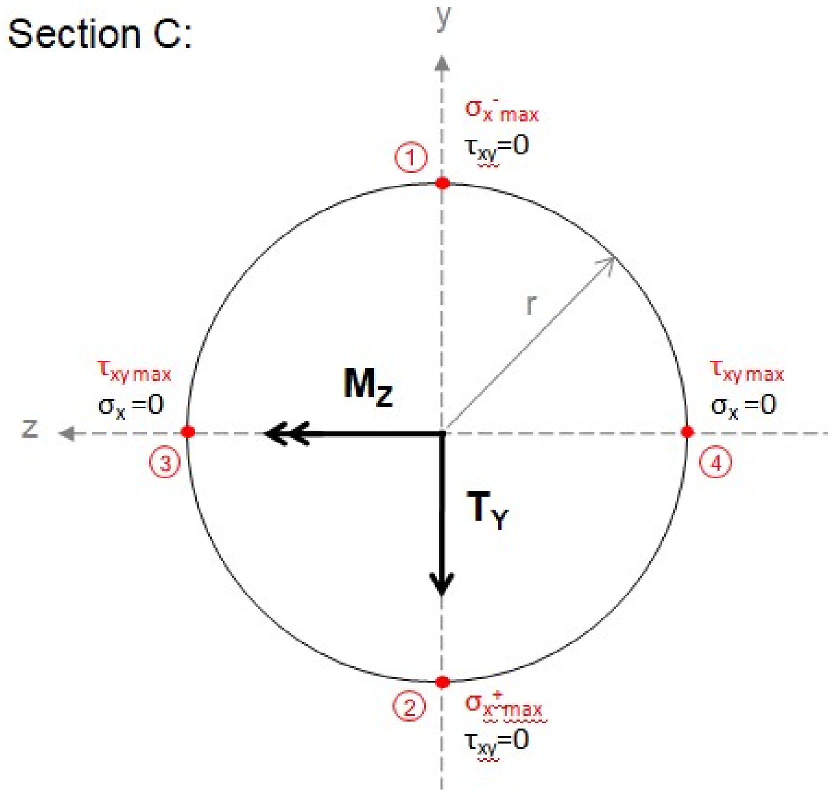


Figure 43 Diagram of the parameters and critical points of section C

This being said, the dimensioning of the section is done using the parameters of the section to calculate the mass moment of inertia of a circumference [Eq.9], and then the maximum bending momentum and Navier's equation [Eq.10] to find $\sigma_{x\,max}$. Since it is a fragile material, the selected failure criteria would be Rankine's [Eq.11], and finally the parameters of the chosen material (the yield strength) and the security coefficient (normally $1,5 \leq \gamma_s \leq 2,5$) would determine the boundary admissible stress [Eq.12] to obtain the ideal radius.

$$I_z = \frac{\pi \cdot r^4}{4} \qquad [Eq. 9]$$

$$\sigma_{x\,max} = \left|\frac{-M_z}{W_{z\,max}}\right| = \left|\frac{-M_z}{I_z} \cdot y_{max}\right| \qquad [Eq. 10]$$

$$\sigma_{x\,max} = \frac{4 \cdot M_z}{\pi \cdot r^3}$$

$$\sigma_{eq} = \max(|\sigma_I|, |\sigma_{III}|) \qquad [Eq. 11]$$

$$[\sigma]_{1,2} = \begin{pmatrix} \sigma_{x\,max} & 0 \\ 0 & 0 \end{pmatrix}$$

$$\sigma_{eq1,2} = \sigma_{x\,max}$$

$$\sigma_{adm} = \frac{\sigma_e}{\gamma_s} \geq \sigma_{eq\,1,2} \quad [Eq.\,12]$$

$$\frac{39{,}95}{1{,}5} = \frac{4 \cdot 89232}{\pi \cdot r^3} \rightarrow r = 16{,}22mm$$

It is important to use a security coefficient, in this case equal to 1,5; to ensure a good performance of the bar knowing but even more in this case where the material has fibres that are not perfectly parallel and can even contain knots. Despite having dimensioned the section considering the points with maximum normal stress, it is necessary to verify that the shear stress of points 3 and 4 still stays within the limitations using the deduction of Collignon [Eq.13]. When imposing r=16,22mm, we can verify that the boundaries are met more than perfectly,

$$[\sigma]_{3,4} = \begin{pmatrix} 0 & \tau_{xy\,max} \\ \tau_{xy\,max} & 0 \end{pmatrix} = \begin{pmatrix} \tau_{xy\,max} & 0 \\ 0 & \tau_{xy\,max} \end{pmatrix}$$

$$\sigma_{eq3,4} = \tau_{xy\,max}$$

$$\tau_{xy} = \frac{4}{3}\frac{T_y}{A}\left(1 - \frac{y^2}{r^2}\right);\ \tau_{xy\,max} = \frac{4}{3}\frac{T_y}{A} \quad [Eq.\,13]$$

$$\sigma_{eq\ \ ,4} = \tau_{xy\,max} = \frac{4}{3}\frac{148{,}72}{\pi \cdot 16{,}22^2} = 0{,}24\ MPa < \sigma_{adm}$$

4.3.3. Displacement analysis

In this section it is intended to study the maximum displacement the superior bar can suffer in the case that a child applies F_{nom}. Since it is a straight bar, the boundary displacement value is normally determined as $v_{max} \leq \frac{L}{100}$, and should by no means be surpassed because the bar could fail.

To obtain more precise results, this will be done firstly through a more theoretical way with Castigliano's Theorem, but then using Solidworks' simulator which uses a finite element method.

4.3.3.1. Displacement analysis with Castigliano's Theorem

This energetic theorem of Castigliano [Eq. 14] states that the partial derivate of the total deformation energy with respect to the applied load, is equal to the displacement δ of the entire load in the direction it is applied. However it is only valid if the following hypotheses are accomplished:

- An elastic and linear behaviour of the material
- Small deformations and displacements
- A conservative system

In this particular case of study all of them can be considered true if the fibres of the bamboo are oriented perpendicularly to the direction of application of the load, hence we can approximate this to a linear behaviour. As a result, the theorem applied to prismatic pieces that are under a plane stress state, taking into consideration a positive displacement in the sense of the applied load, the formula is:

$$\delta = \frac{dW_{Total}}{dP} = \int_0^s \left(\frac{N}{E \cdot A} \cdot \frac{dN}{dP} + \frac{T}{G \cdot A_1} \cdot \frac{dT}{dP} + \frac{M}{E \cdot I_z} \cdot \frac{dM}{dP} \right) ds \qquad [Eq. 14]$$

Considering:

$E = 17500 \text{ MPa}$

$G = \frac{E}{2 \cdot (1 + v)} = \frac{17500}{2 \cdot (1 + 0{,}32)} = 6730{,}77 \text{ MPa}$

$A = \pi \cdot r^2 = 826{,}52 \text{ mm}^2$

$I_z = \frac{\pi \cdot r^4}{4} = 54361{,}7 \text{ mm}^4$

$A_1 = \frac{9}{10} \cdot A = 743{,}87 \text{ mm}^2$; A_1 being the reduced area

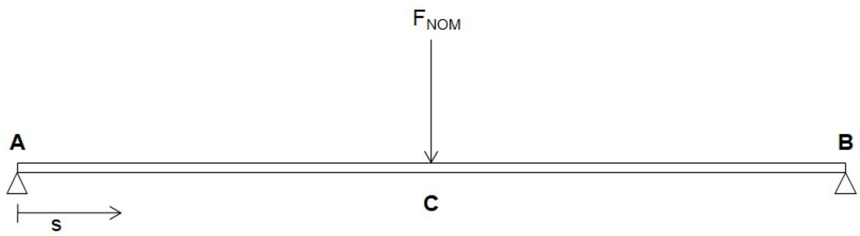


Figure 44 Sketch of coordinates of the bar

Table 4 Stress and differential stress applied in each section of the bar

Section	N	T	dT/dF	M	dM/dF
AC 0 ≤ s ≤ 600	0	$\frac{1}{2} \cdot F$	$\frac{1}{2}$	$\frac{1}{2} \cdot F \cdot s$	$\frac{1}{2} \cdot s$
CB 600 ≤ s ≤ 1200	0	$-\frac{1}{2} \cdot F$	$-\frac{1}{2}$	$\frac{1}{2} \cdot F \cdot s - F(s - 600)$	$\frac{1}{2} \cdot s - (s - 600)$

$$\delta_{AC} = \int_A^C \left(\frac{N_{AC}}{E \cdot A} \cdot \frac{dN_{AC}}{dP} + \frac{T_{AC}}{G \cdot A_1} \cdot \frac{dT_{AC}}{dP} + \frac{M_{AC}}{E \cdot I_z} \cdot \frac{dM_{AC}}{dP} \right) ds$$

$$\delta_{CB} = \int_C^B \left(\frac{N_{CB}}{E \cdot A} \cdot \frac{dN_{CB}}{dP} + \frac{T_{CB}}{G \cdot A_1} \cdot \frac{dT_{CB}}{dP} + \frac{M_{CB}}{E \cdot I_z} \cdot \frac{dM_{CB}}{dP} \right) ds$$

$$\delta_{total} = \delta_{AC} + \delta_{CB}$$

$$\delta_{AC} = \int_0^{600} \left(0 + \frac{\frac{1}{2} \cdot 297{,}44}{6730{,}77 \cdot 743{,}87} \cdot \frac{1}{2} + \frac{\frac{1}{2} \cdot 297{,}44 \cdot s}{17500 \cdot 54361{,}7} \cdot \frac{1}{2} \cdot s \right) ds = 5{,}64 \text{ mm}$$

$$\delta_{CB} = \int_{600}^{1200} \left(0 + \frac{-\frac{1}{2} \cdot 297{,}44}{6730{,}77 \cdot 743{,}87} \cdot \frac{-1}{2} + \frac{-\frac{1}{2} \cdot 297{,}44 \cdot s + 600 \cdot F}{17500 \cdot 54361{,}7} \cdot \left(\frac{-1}{2} \cdot s + 600 \right) \right) ds = 5{,}64 \text{ mm}$$

$$\delta_{total} = 5{,}64 + 5{,}64 = 11{,}28\text{mm}$$

$$\delta_{total} = 11{,}28\text{mm} < \delta_{max} = 12\text{mm}$$

4.3.3.2. Displacement analysis through simulation

As an additional method and to computationally verify the results obtained from directly applying the expressions of resistance, a finite element simulation is done using the software Solidworks Simulation. This method allows discretizing the piece into multiple smaller elements by meshing it and then applying the equations to each node.

Despite thinking that a child normally hangs himself from an object applying a sudden load on it, while doing an initial dynamic simulation it was observed that the displacement value didn't vary much therefore to simplify the analysis, an statistic linear study has been carried out. This consists of considering that the restrictions and the load are constant throughout time and are applied progressively.

Moreover, the material used is bamboo determined with the mechanical parameters established in [4.2.2.1] and as and isotropic material since the fibres are oriented perpendicular to the application of the load and parallel to the longitudinal axis. Regardless being held by two hooks, one point of each end surface is fixed in all 3 directions. Referring to the external loads, the equivalent load to a child's weight (F_{NOM}) is placed in a differential surface in the centre of the top edge of the bar. Finally, a mesh with curve elements is used to obtain a better adjustment to the rounded surface; being the elements of size 10mm, since the smaller the size the more precise results are reached. It is also important to apply a control on the mesh (elements of 2,5mm) in the area where the load is applied to avoid a big jump compared with the values obtained along the rest of the object.

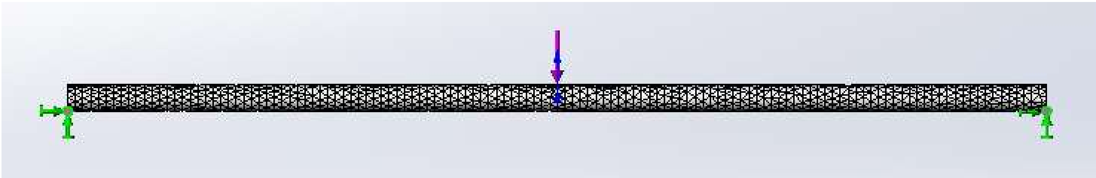


Figure 45 Mesh and restrictions applied to the bar

As a result, the maximum displacement obtained from applying the force F_{NOM} to the bar is 11,1mm in the section where the load is located. Despite this value is inside the boundaries ($11{,}1\text{mm} < \delta_{\max} = 12\text{mm}$), it doesn't perfectly match with the one obtained by Castigliano's theorem. Nevertheless, the relative error is 1,6%, which is so small that can be considered as a correct displacement value. This deviation can be due to the precision of the mesh, or the placement of the restrictions and the load since being a curve surface makes it harder to be exact.

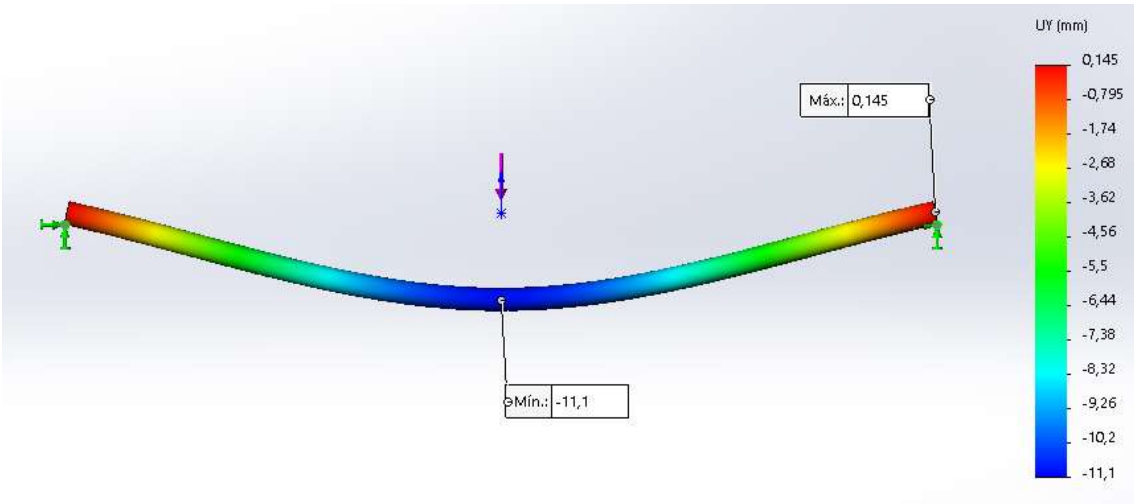


Figure 46 Displacements in the direction of the Y axis

After checking through two different ways the maximum displacement of the bar in case a child hung himself, and seeing that the mean value 11,2 mm stays always inside the superior limit of 12mm, it can be confirmed that both bars not only fulfill the criteria of stiffness, but also of resistance.

4.4. Design optimization

The dimensions used to create the first real scale prototype were defined according to the space and requirements, although since the resources weren't many, they could be readjusted to make its manufacture easier. Another important point of study is the union between layers since after the prototype validation process some failures were detected.

4.4.1. Measurement specifications

Being the main objective to showcase student's work, the intention is to make it as big as possible to enlarge as much the surface of use, but always taking into consideration the restrictions of space, but most importantly of use. It is essential that the object can be carried around easily, stored without taking much space and reached by kids of all ages. The dimensions of the object have been determined based on the environment it is designed for. Since all bridge schools are built with the same panels and architecture, adapting the prototype to one of them would make it perfectly modular to be used in any other school.

Therefore, the main parameters to take into consideration are the height and the maximum width of the walls, to ensure the board can be hung anywhere around the space. Regarding the height, since it is designed to be hung from some hooks that hold on to the upper edge of the walls, a margin is needed to guarantee that the board reaches the floor so that students and teachers can access it, but without getting wrinkled because it is too long. Moreover, as concluded after a conversation with the teacher, one of the best places to set the board would be the entrance door which is a point that can be seen both from indoors and outdoors.

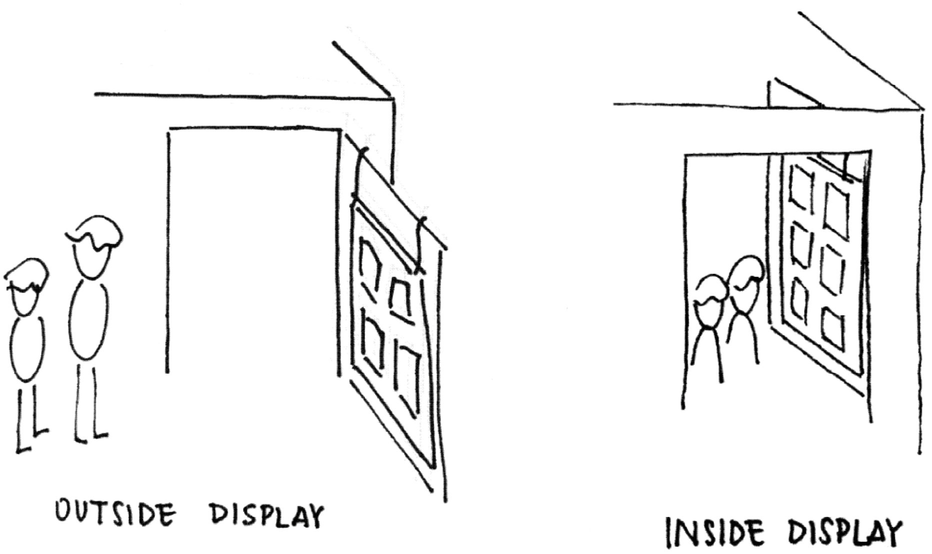


Figure 47 Exterior and interior disposition of the board on the door

Knowing that the measurements of the height and width of the wall panels are approximately 2,5m and 2m respectively, but that the door is slightly smaller (2x1,5m), the dimensions of the board should be adapted according to it. The hooks that are provided to each bridge school together with the rest of the material and furniture, are about 30cm long, thus the length of the prototype should be 1,7m. It is also necessary to leave a margin of 15cm on both sides so as to avoid having the drawings caught when closing the door, resulting in a breadth of 1,2m.

Even if the board will be usually held by both ends with hooks, there is a ribbon that serves as handle for transportation. It is not recommended to use it as an alternative hanging method since it hasn't been dimensioned accordingly and in the hypothetic situation that a kid hung himself from the board, the handle could let loose and the object could fall. Nevertheless, the ribbon's length must be calculated so as to avoid grazing the ground if this scenario was given.

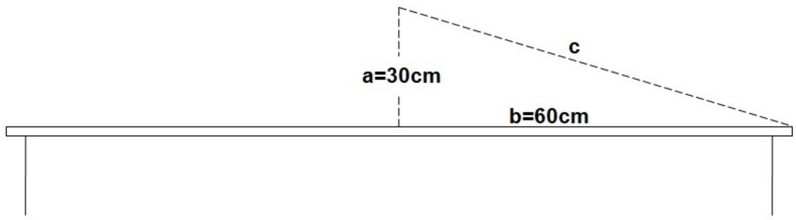


Figure 48 Measurements specifications for the length of the ribbon

$$c = \sqrt{a^2 + b^2} = \sqrt{0{,}3^2 + 0{,}6^2} = 0{,}67\text{m} \qquad [\text{Eq. } 15]$$

$$\text{Length ribbon} = 2 \cdot c + 2 \cdot \text{diameter} = 1{,}405\text{m}$$

Since there is some space needed at both ends of the top bar to attach the handle, the width of the other three layers will be narrower and equal to 1,10m. Moreover, there are other details, like the blackboard, that need to be specified. Even if it hasn't been thoroughly studied, the ideal would be to have a 1x1m long flexible blackboard sawn to the top part, that would allow the teacher to have enough space for explanations, but that could then be folded up to enable seeing students' artwork. As it was already tested with the initial prototype, the blackboard would have velco pieces sawn along the edge to be able to fold it up in two smaller sizes. The main idea is to unfold the surface for the teacher to draw on at the beginning so that children understand well the task, but once the activity is finished, the board can be folded up just to serve as a title or a brief explanation to introduce the displayed work.

Knowing from the experience achieved during the field visits at the bridge schools, students normally used A5 size paper (148mm x 210mm) to do their work on. Taking into account a vertical margin of 20-30mm between them and that the board is folded when they are displayed, the capacity of the prototype can be calculated depending on the orientation of the drawings. If the artwork if placed horizontally, there is a limit of 8 rows on the front and 10 on the back, with 5 papers per row, adding up to a maximum volume of 90 pieces. In the case of vertically oriented papers, there is space available on each line for 7 pieces, having a maximum range of 6 rows on the front side and 7 on the back, which gives a total amount of 91 divisions for artwork.

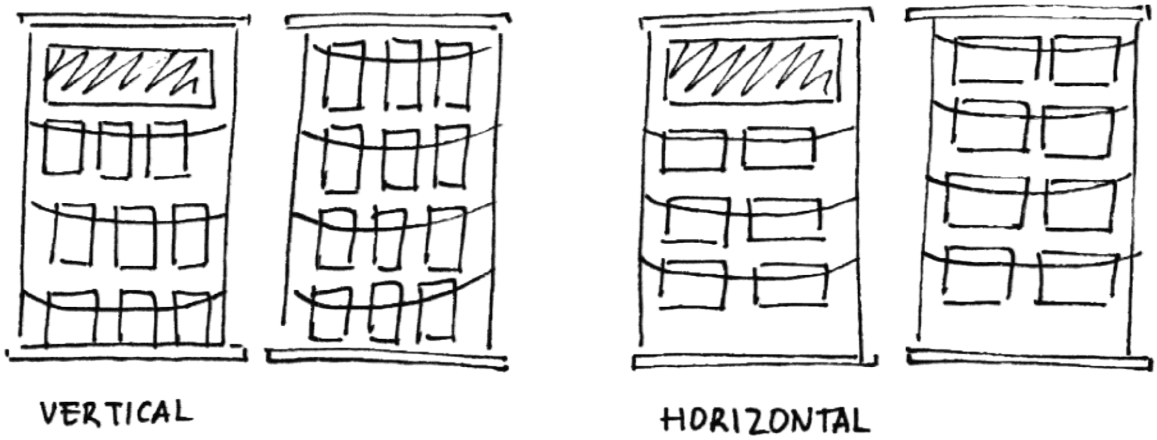


Figure 49 Available ways of displaying the artwork

Since the capacity of students in a bridge school can vary from 15 up to even 60 students, and knowing that each prototype can showcase a maximum of 90 pieces of work approximately, with only one board would be enough to cover the whole school. Nevertheless, since the paper sizes can vary, there will be a total of 15 eyelets per side equally distributed along the edge so that the teacher can adapt the strings in each case to the number and size of students' work.

4.4.2. Junction system

To make the object as simple as possible and with the fewer junction points, rather than using a special glue for these kind of surfaces than can burn the plastic and in long term crack and fail, a new system has been invented. This method consists of folding the superior and inferior edges of the main surface approximately 35mm (leaving some margin for the stitches) and sawing them down to create a tube through which the bars can be inserted. The cover sheet can then be placed on top and simply fixed to the board with a seam. To ensure the bars don't slide out, two rubber blocks are placed on the ends of each bar. However, they wouldn't only stop the bars from falling out but also prevent sharp edges that could be dangerous in such an environment where kids are constantly moving around and playing with everything.

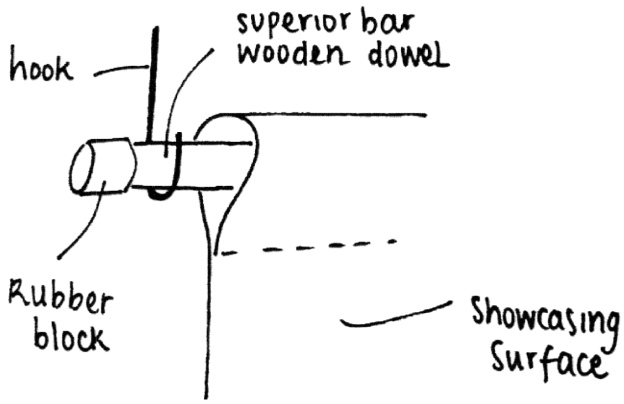


Figure 50 Junction system sketch

The ideal would be that the rubber caps stayed in place only due to their own pressure, since the friction between rubber and bamboo would stop them from falling out. However, this can't be verified until a real scale prototype is built, thus, in the case that this hypothesis is not proven, a drop of glue could be used to hold both pieces together. Given that there aren't any forces applied on the blocks, the only requirements the adhesive should contemplate are having a working range of temperatures of 0-60°C, and being adequate for rubber and bamboo.

In reference to the stitches, the ones that are used to attach the ribbon to the perimeter of the tissue and to the plastic layer to avoid sharp edges, or the ones that hold the straps, can be regular seams because they aren't put through any stress circumstances. In spite of this, the superior and inferior loops of the fabric that are sawn together, have to sustain the own weight of the object as well as the hypothetic case of a child pulling the tissue. To avoid a situation where the stitches pop and the board breaks down to peaces causing a possible danger if falling on a child, these two seams have to be specially taken care off. The key parameters that intervene are: the type of thread, the tension of the thread and the type of seam. A possible way to reinforce this junction points would be to apply an overload stitch, which is commonly known to be the most resistant one and is suitable for all types of thicknesses. It is also essential to always sew up the ends to avoid the seam from opening up; this is done by stitching forward and backwards at the beginning and end of each seam.

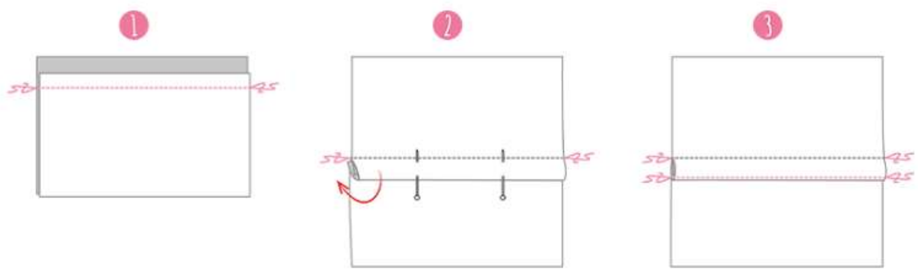
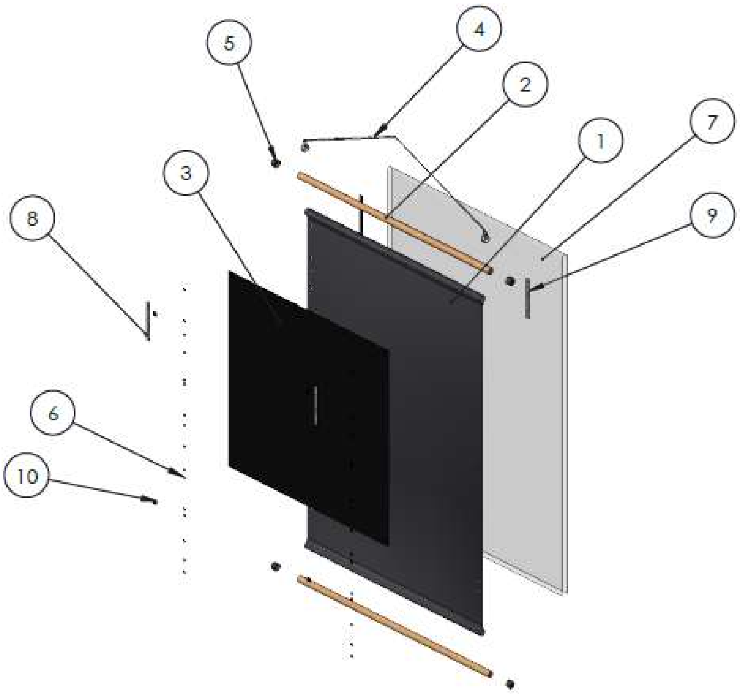


Figure 51 Steps to achieve an overload stitch

4.4.3. Final design

4.4.3.1. List of components

To be able to produce the board it is necessary to have all the components available, which are specified in the following image. Nevertheless, having the materials doesn't guarantee anything; there is also the necessity to have access to a tailor and a carpenter, as well as an additional worker that assembles the final pieces.



ELEMENT NUMBER	DESCRIPTION	UNITS
1	Fabric surface	1
2	Bamboo bars	2
3	Blackboard	1
4	Handle	1
5	Rubber blocks	4
6	Eyelets	32
7	Plastic cover	1
8	Individual strap	2
9	Double strap	2
10	Velcro pieces	4

Figure 52 List of components

4.4.3.2. General dimensions

Putting together all the details outlined in the sections above, the final measurements of the board are specified in the blueprints located in section [0] of the appendix. Since there are a large amount of different pieces, there is a distinction between three different layers:

- Layer one: contains the measurements related to base of the board including the fabric surface, the bars, the strap and the rubber blocks.
- Layer two: contains the measurements related to the components that are fixed onto the fabric surface, such as the blackboard and the velcro pieces, the eyelets and the straps.
- Layer three: contains the measurements related to the plastic cover.

The following images identify the main measurements discussed before, to give a general overview of the model.

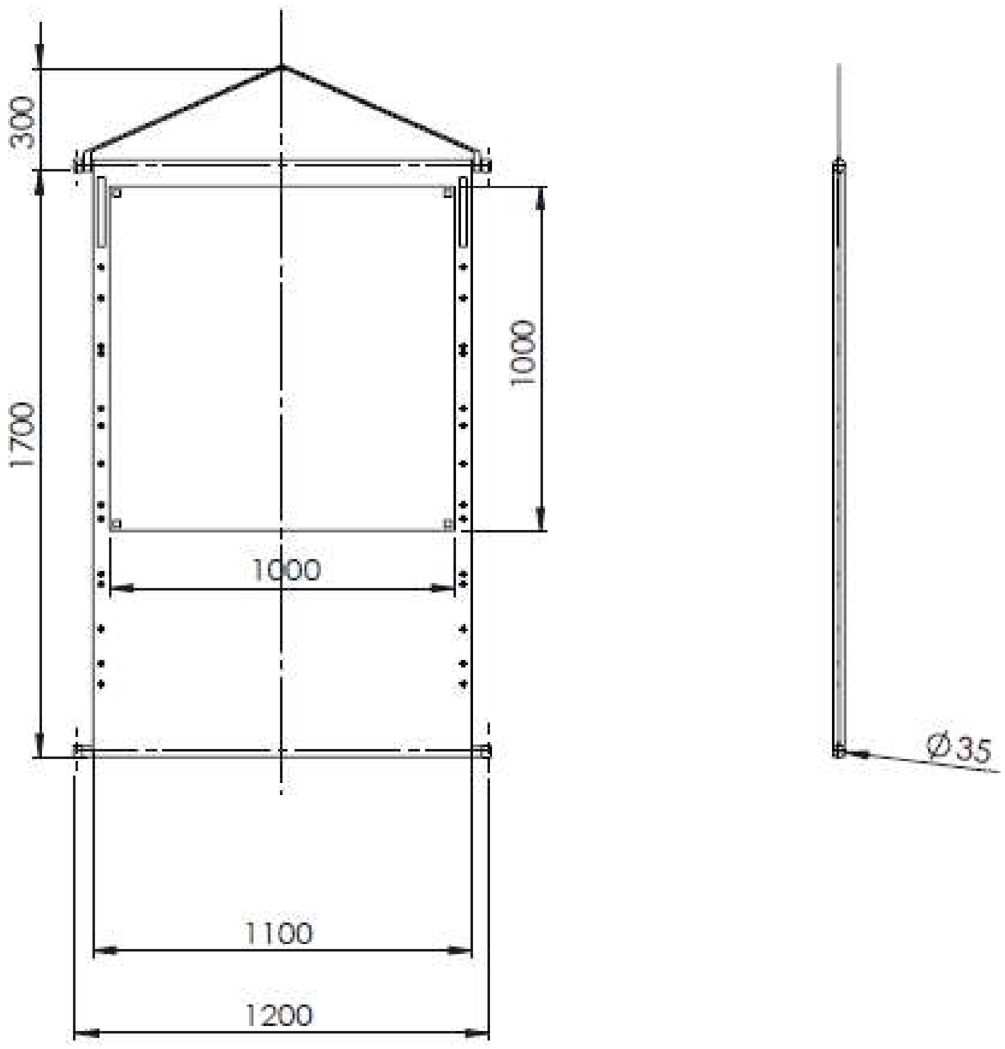


Figure 53 Frontal and side general dimensions

One of the main requirements tested when choosing the materials was to minimize the mass as much as possible so as to be able to transport it easily. This is indeed verified since the total weight of the object is 3,78 kg, which is broken down into the specific parts in the following table:

Table 5 Weight quotations of the board

Parts	Measurement	Weight
2 bars	700 kg/m^3	1,39 kg
Fabric board	970 kg/m^3	0,54 kg
Plastic sheet	1070 kg/m^3	1,31 kg
Blackboard	1070 kg/m^3	0,21 kg
4 rubber blocks	0,01 kg/bloc	0,04 kg
Handle and straps	0,02 kg/m	0,05 kg
20m string	0,0035kg/m	0,07 kg
32 eyelets	0,005 kg/eyelet	0,16 kg
4 Velcro pieces	0,12 kg/m	0,0096 kg
TOTAL WEIGHT		3,78 kg

4.4.3.3. Instructions of use

As it has already been mentioned before, the object is modular which means it offers a variety of different positions. The design has decided to adapt to each way of use to make it as comfortable as possible for the user at all times.

In the first place, to store and transport the item, there are some straps that allow tying the rolled up pieces, turning the object into a compact cylinder which can be easily carried using the handle.

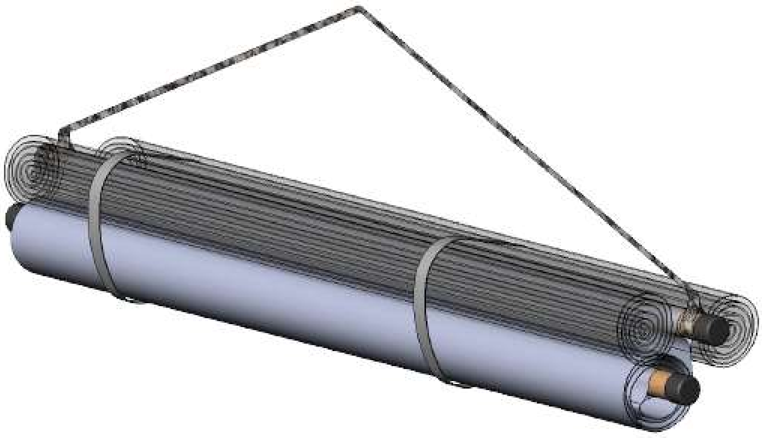


Figure 54 Method of use 1: rolled-up board

Moreover, when using the board there are two possibilities depending on the environment it is located. If the surface is being used by the teacher to explain something or by the children to hang up some work, then the plastic cover can be rolled up and sustained at the top bar. However, if it is used to showcase some artwork, especially in exterior spaces, it is advisable to roll down the cover to protect the contents from atmospheric conditions, rural environments or just from people touching the work and damaging it.

Figure 55 Method of use 2: blackboard positions

Finally, regarding the activity that takes place involving the teacher and the students, the blackboard has three possible measurements. If it is completely extended, it would be usually used by the teacher to explain an activity on it, whereas if it is folded in half or in a quarter, it would be usually used as a heading to indicate some brief information about the work that is being showcased.

Figure 56 Method of use 3: cover positions

5. Viability study

5.1. Manufacture

5.1.1. Manufacture process

Given the fact that this object is intended to be produced by local communities in India, both the design and manufacture have to be as simple as possible to minimize costs and time. To achieve this, not only the measurements are as rounded as possible, but also the number of materials involved has been reduced and the machinery and components needed to produce the board is commonly found. Moreover, to ensure this process is fast and easy, when choosing the materials, a restriction regarding good processability has been applied. As a result, following the dimensions specified in the appendix [0], the process is the following:

Step 1:

Cutting 2 blocks of bamboo to a length of 1200mm.

Step 2:

Turning operation, more specifically surfacing, to obtain the desired diameters of 32,5mm. An additional truing process can be done to polish the surfaces so as to get rid from possible splinters thus obtain a better surface appearance.

Step 3:

Cutting to size the main tissue surface (1200 x 1875 mm) as well as the protection cover (1200 x 3502 mm). The measurements are enlarged according to the necessary margins needed for the loops.

Step 4:

Sawing a ribbon all along the perimeter of the plastic cover and tissue surface to avoid sharp edges.

Step 5:

Folding the superior and inferior edges of the tissue to create 2 loops of diameter 32,5mm and sawing them down.

Step 6:

Cutting 5 pieces of ribbon: a long one of 1405mm for the top handle, two medium ones of 400mm for the back side straps and two shorter ones of 200mm for the front side straps. Sawing two loops of 32,5mm of diameter at the ends of the long piece.

Step 7:

Stitching the blackboard in place, on the superior part of the main surface and attaching the 4 velco pieces (2x2 cm) on the top and bottom corners of the front side and on the middle and bottom corners of the back side.

Step 8:

Sawing the cover to the tissue layer using a stitch along the top edge

Step 9:

Stitching the 40cm long ribbon straps folded in half on the back side of the main surface and the 20cm long ones on the front side.

Step 10:

Piercing out 15 holes on each side of the tissue and adding the corresponding eyelets.

Step 11:

Inserting both bars, sliding in both ends of the handle along the superior bar, and adding in the rubber blocks (if needed add some wood glue to stop the rubber blocks from falling off).

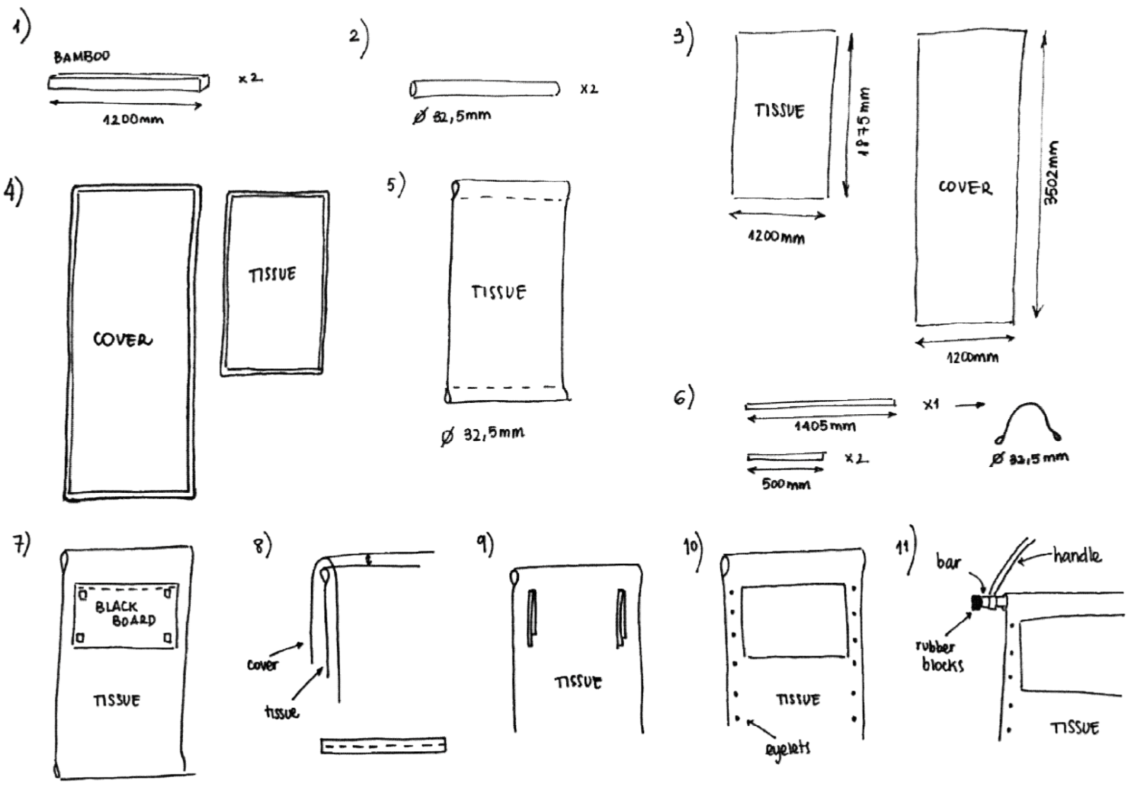


Figure 57 Manufacture process

5.1.2. Ecological footprint

Even if the manufacture process is quite simple, it is also important to take into account the repercussion it can have on the surroundings. For this reason, not only some materials are easily found locally like bamboo, but also all the people involved in the production of the object are local artisans to make the board a Km0 product as much as possible.

During the assembly of the product, there are clearly some CO_2 emissions that have to be controlled, although while extracting and preparing the materials for its manufacture there is also a considerably large amount of emissions that we often forget off. Since these calculations are hard to specify without exactly knowing the type of machinery and processes that would take place, a general approximation is done putting all the components into the following 4 main groups.

Table 6 Carbon dioxide footprint resulting from the board production

Material	Primary material production (kg CO_2/kg)	Total CO_2 emission material production (kg CO_2)	Material processing (kg CO_2/kg)	Total CO_2 emission material processing (kg CO_2)
Bamboo	1,05	1,586	0,121	0,183
PVC	2,7	4,212	0,446	0,696
PE	1,86	0,614	0,0543	0,018
CE	3,405	1,124	0,0682	0,023
TOTAL		7,536		0,92

The transportation emissions are quite low and can considered as 0,05kg CO_2/board. Consequently the total carbon dioxide emissions would be around 8,51 kg CO_2 per board, whilst normally with the production of several units in a row it would be reduced.

Furthermore, even if the impact that the production of the object has needs to be controlled, another aspect that should be accounted for is the consequences that this can have once the board cannot be used anymore. Thanks to the high resistance of the materials and mainly the protection guaranteed by the cover, the board is intended to last very long, which reduces significantly the energy consumption and the emissions of the post processes. Another point to emphasize is the simple and fast disassembly of all parts since all junctions are either done with a stitch or by fitting together two pieces.

Luckily bamboo is biodegradable and a fast growing renewable resource which makes it very attractive from an ecological standpoint. Regarding all the different fibers involved in the main tissue surface, the handle and the straps, some components like cellulose are biodegradable too, although others aren't.

However, all of them can be easily recycled and combusted for energy recovery, but the most suitable option would be to reuse them to produce some of the many pieces of the textile industry. Finally, despite not being able to place the plastic from the cover, the blackboard and the rubber blocks in a landfill, if they are deposited in the correct areas, it’s recycling process can be safely carried out with approximately 1,13 kg CO_2 emitted per kg of PVC.

5.2. Budget

Another key aspect that should be checked is the total cost the object would have since it mustn't be too elevated. Materials have already been chosen with price restrictions and no margin would be applied since it's a non-profit product.

Table 7 Breakdown of costs of production of the board

Components	Unit price	Total price
Bamboo	123₹/kg	170,97₹
Fabric	200₹	108₹
PVC sheet	189₹/kg	247,59₹
Blackboard	80₹	80₹
Rubber blocks	26₹/block	104₹
Handle and straps	35₹/m	87,5₹
20m string	3,8₹/m	76₹
32 eyelets	0,61 ₹/eyelet	19,52₹
Velcro	85 ₹/m	6,8 ₹
Bamboo manufacture	200₹/h	100₹
Tailor	500₹/h	375₹
Assembly	75₹/h	37,5₹
TOTAL		1411,66₹

In this case, prices are estimated according to the Indian since the production is intended to be done on site, thus the total amount converted into Euros would be 16,47€. Nevertheless, this price could be significantly reduced when buying larger quantities of aforementioned materials.

In normal cases, this amount would also include the hours of work invested in elaborating this report. Nonetheless, since the aim of the project is to help communities develop a basic need, which is education, the study is completely non-profit and the services implied are not remunerated.

CONCLUSIONS

Going back to the beginning of the project, it has been proven that all the set objectives have been accomplished. The main objective was to design a prototype that improves academic comfort in bridge schools by enhancing students' self-esteem. Even if it is hard to understand how this is possible just by writing some pages, all the secondary goals help back-up this idea.

In the first place, during the trip to India where this project started, a very thorough, but essential, analysis was carried out. It has been fundamental to understand the context and to always have in mind the target beneficiaries and their corresponding needs. The continuous feedback from experts, organizers, users and collaborators made it possible to develop a human centred design according to the observed problematic from the very first moment.

Once having developed the first real scale prototype, there were still many aspects, mainly technical ones, that needed to be studied in depth. Researching for alternative materials and elaborating a resistance study narrowed down the vast design possibilities. Moreover, it was also a way to discover unknown options such as the use of bamboo, which match perfectly with the initial idea of obtaining an object that is manufactured as a whole in India, using as much local raw materials and workforce as possible. Rethinking the design of the board has pushed the boundaries to find a much more suitable object in terms of adaptation to the environment of use as well as to the space and the beneficiaries. Details have been meticulously studied in most cases to avoid potentially dangerous situations and reduce as much as possible the manufacture difficulties, so as to obtain the perfect combination of light, modular, safe and valuable in one same product.

Further analyzing the impact, both from economical and environmental points of view, has given the design a much more real and tangible nature. Altogether, this work has enlarged the scope and possibilities of implementing such a solution in a near future. There are still many points that could be investigated on, as well as others were further tests should be carried out, however this project has opened up many new doors. Even if setting as an objective to raise awareness about education in slums in India could sound overambitious, just by developing such an analysis you are encouraging new generations to recognize the importance of social innovation.

Nowadays, we have the means to communicate all around the world, we have amazing technologies that allow us to reach the unreachable, but most importantly we have the knowledge to be able to focus our efforts into building a better global community. Despite this, not everyone has access to this vast amount of tools and capacities, so it is then our duty to give them a helping hand. Implementing this particular solution in several bridge schools located in underdeveloped areas, like slums, in India, would not only increase in short term the enthusiasm of children to go to school, but would grant them in long term great future opportunities. Being the fear of parents to allow their children to go to school one of the main triggers of this project, it can now be proven that by showcasing student's work, they would be getting involved in their education and understanding the importance it has in early ages. By opening up to the community, bridge schools will be able to grant access to many more children in need, giving them basic knowledge that can then be their ticket to enter government schools. If this is achieved, in the future many more bridge schools could be built to give new opportunities all around the country and those kids who in the first place had the chance to attend one, would now be the ones setting an example.

ACKNOWLEDGMENTS

When the time to elaborate this project approached, the only things that really existed were plenty of ideas in my head that span around the same topic but lacked connection between them. However, thanks to my two directors, all these thoughts have been structured and have become something much more tangible.

At the beginning of the path I only had by my side Arantza as my tutor, but halfway through, I contacted Elisa, who without even knowing me or my project trusted immediately in it. She quickly accepted my offer to participate and has been a great help all the way along. Nevertheless, I must also emphasize Arantza's support at all moments; we quickly got to know each other and she has been involved from the very first day. She has treated this project as if it was her very own and has encouraged me during every single step, assisting me in all sort of issues.

Without both of them, this project wouldn't be the same, but what is more, the experience of elaborating it would have been completely different. For this reason, I want to truly thank both of them.

Furthermore, I must not forget all the people from EPFL, who gave me the opportunity to participate in the immensely enriching experience of travelling to India to join INSSIC (India Switzerland Social Innovation Camp). This journey not only helped me to enlarge my knowledge, but made me grow as a better person and guide a bit more my future goals. Despite having a great organizing team, the participants of the camp were also amazing people with whom I got to share this very enriching experience. Despite our differences o gender, nationality or habits, we managed to work perfectly as a team; especially with Iscia and Romain who were my partners in this idea. Even if I elaborated this report as an extension of the initial proposition, we developed the whole initial model together, which we then continued working on by submitting an entry to a competition or writing some articles to document it.

On the other side, I have also had the support from some members of the faculty of ETSEIB, as well as from UPC. I am also grateful for that, since all the years of study in this institution have now proven that it wasn't only the education I received, but also the people behind it.

Finally, family and friends have been as always a fundamental pillar in my life, who have accompanied and reassured me every single moment, especially during these harder months of confinement.

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