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MOTIVATING ENGINEERING STUDENTS ON USING CIRCULAR ECONOMY FOR THE DEVELOPMENT OF LOW-COST ACOUSTIC MATERIALS

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Abstract

This paper presents a recent experience of working with intermediate-advanced students of Civil Engineering, who converge in a curricular Workshop on Environmental Engineering. The topic to be worked on during the workshop was to improve the acoustic quality of a multipurpose space that is very popular among students for group studying, and near which there is a lightly built office block, distributed over five floors. The high noise levels in this place not only negatively affect the use of time by the students, but also that of the teachers who work in that office block. By proposing this topic for the 2021 academic course, the students already had a clear experience of the proposed case study, despite the fact that due to the health emergency that the world has been experiencing for more than a year, there have been neither face-to-face classes nor authorization for massive use of study places. In addition, some of the students had taken subjects that brought them closer to the basic concepts of acoustics and integral solid waste management.

The multipurpose space is equipped with mobile panels (with small wheels) that have, on both sides, an upper part intended for a whiteboard and the other covered with felt. A first approach was made to the possibilities of modifying the design of the panels to incorporate a head -in the style of those used in acoustic screens-, rather parabolic in shape and with its lower face protected with a sound-absorbing material. In a second instance, possible suitable materials were analyzed to be used in that face of the head and in the lower part of the mobile panels.

At the very beginning, the wide variety of options ranging from living plant absorbents to sophisticated commercial materials. However, by conducting a quick cost analysis, the students suggested the possibility of developing their own materials from waste. The idea arose from a set of panels developed some years ago by a Design student in her graduation thesis. She created low-cost panels from wool waste generated by the weavers of Manos del Uruguay, a national company of high-quality handmade products.

Those panels achieved good acoustic performance and were tested to confirm that they were fireproof. In the current case, the identification of common urban solid waste was prioritized, preferably that generated at home or at the Faculty, to potentially be used as raw material to obtain acoustic absorbent materials. Among the options that were considered, non-directly recyclable paper (for example, due to its coating) and the results of document shredders were found to be the most abundant; the first ones are usually generated at home and the others, in the Faculty offices. When working with paper waste, the goal is to create lightweight, airy panels with rough or textured surfaces. A second option was to deepen the work with textile waste materials; in this case, the possible difficulty would be to access the waste.

The work of the students involved the next steps: diagnosing the current situation; designing the solution; making some samples of the acoustic panels made by paper wastes, in order to test their acoustic properties; calculating their acoustic absorption coefficients; proposing the solution to be implemented, its cost and the time for putting it into practice. The students based their option by trying waste-based materials on the need to reduce the amount of wastes, knowing that they would not solve the problem but they “lead by example”. They achieved a very good acoustic response of the panels, so they suggested to the Faculty authorities to use these kind of panels, placed into canvas containers; these bags or containers improve the acoustic absorption performance of the panels and allow to wash the bags. However, it is possible that the final decision of the institutional authorities will not be in favour of using hand-made recycled panels as part of the furnishings for the multipurpose space.

1. INTRODUCTION

In the curriculum to become a Civil Engineering in Faculty of Engineering (FING) of UdelaR, practical subjects for bringing environmental issues closer to students, are recommended. One of these subjects is the Environmental Engineering Workshop Module (MTEIA). It lasts one semester. This workshop addresses problems that challenge students and teachers, working as a team to propose solutions to real life problems, improving understanding and communicating a relevant problem. The main novel activity in this subject is that the students have to “write the statement of the exercise” to be solved during the course, turning a student's approach into the case study. The selection of the approach methodology, the study of regional precedent experience about the topic, the performance of practical tasks and the oral presentation of a final report make up the dynamics of the course.

The topic addressed in the edition of the first semester of MTEIA 2021, was improving the acoustics conditioning of the so-called “Green Floor”, a public multipurpose space mainly used for studying and holding events at the Faculty (FING-Udelar). That is, the main objective will be contributing to the continuous improvement of the environmental conditions of work and study in FING-UdelaR, by defining proposals for acoustic improvement of some spaces. To tackle the task, the development of a four-stage methodology was proposed: 1. Select the case study, 2. Define the detailed methodology to be carried out, 3. Analyze the obtained results, 4. Identify opportunities for improvement and pre-design possible solutions.

2. PREVIOUS WORK

2.1. BACKGROUND

The project “Management of waste similar to domestic ones at Universidad de la República. Survey of every UdelaR sections” [1] was carried out from May to July 2014. It aimed to know about the waste management practices in UdelaR, in order to establish recommendations according to the current regulatory framework. The survey was designed by the team of the Environmental Engineering Department, IMFIA-FING-UdelaR. It was conducted in the different sections of the University through the Pro-Rectorate of Administrative Management, with the cooperation of the Committee on Processes and Conditions for Studying, Working and Working Places at UdelaR.

The waste management in FING is based on the concepts of Responsible Consumption and the ‘Culture of R's’ (Reuse, Recover, Recycle). Regarding the management of recyclable waste, such as paper and cardboard, these type of wastes have been collected since 2014 in FING, at its different offices and then delivered to the NGO “REPAPEL”. In other words, there are considerable amounts of paper waste generated in daily work activities at the Faculty of Engineering. Currently, paper waste is collected in designated containers. When these containers reach their maximum storage capacity, they are transported to the FING ECOPOINT, which is a storage site for some types of recyclable waste, also located in the FING field. After six years of experience, it is operating fluently and safely.

2.2. CASE STUDY

Universidad de la República (UdelaR) is the oldest University in Uruguay. It has more than 130 years. It is public and free of any kind of charges, what means that the students have nothing to pay for their professional education: it is totally for free. Since the entrance examination was eliminated on 1984, the number of students at UdelaR has been growing and growing, and the FING is not an exception. Then, some years ago the FING decided to offer to the students some spaces for studying at the University, in order to reduce time and costs of commuting, and promoting collaborative learning as students develop a greater sense of belonging to the University. One of these public areas for studying is a big multipurpose place: the “Green Floor” (Figure 1).

The Green Floor is very attractive for students, not only because its large area but also because of its comfort for studying and its visual appeal. It has a lot of tables and chairs which can be easily moved from one place to another, and also many whiteboards with wheels, that are used as barriers for creating small sectors for studying in groups. It is located at the third basement of the main building of FING. It has two entrances, one from the main building of the Faculty and another which directly connects outside the building. This second entrance easies the access from the other buildings of the Faculty that are close to it. As a consequence, the Green Floor not only uses to present a high attendance of students from FING and other UdelaR Faculties, but also many people use it to commute from one building to the next.

This level of continuous activity causes sound pressure levels that can exceed values of L_{AF} of 70 dB. These high sound pressure levels can cause difficulties to the students to concentrate in what they are studying and to communicate with those they are studying with. Also, some conditions as headaches, irritability, anger, anxiety, stress, frustration can appear, as a consequence of the exposure to high sound levels [2].

Figure 1: The Green Floor (in a very quiet time). (Photos from [3])

3. METHODOLOGY AND PROCESS

3.1. LITERATURE REVIEW

The first activity that was proposed to the students was a literature review [4], to reinforce and update basic concepts related to room acoustics. The main topics included: acoustic absorption, acoustic insulation, acoustic diffusion, acoustic barriers and acoustic efficient shapes, as well as some calculation tools for assessing and comparing different solutions.

3.2. DESIGN THINKING PROCESS

A “Design Thinking” workshop was carried out. The dynamic of “the six hats” was put in practice for identifying the main aspects of the problem and those the solution should include, emphasizing on defining the strengths and weaknesses, the opportunities and the hazards. When the pros and cons where fixed, the problem to be addressed was clear: it should be the reduction of reverberation time and perceived sound pressure levels in the studying place [4].

As it was not allowed to fraction the Green Floor or install cubicles, the idea was to increase the acoustic absorption area, especially at the range of frequencies of human voices; and enhancing the wheeled whiteboards behavior as acoustic barriers, to reduce the passage of sound to nearby students who are working on a different topic. Some sketches were drawn while proposing of solutions (Figure 2) and models were even built (Figure 3).

A parabolic appendix was proposed for adding in the upper part of the wheeling whiteboards, and covering the lower part of these mobile barriers with some soft absorbing material. For deciding the best materials to use, the acoustic absorbers possible to buy in Montevideo (Uruguay) and their prices were identified, the most accessible being cotton felt, foam panels, glass wool, rock wool and cork.

Two interviews were also done [4]: Designer Lucía Delgado, author of the thesis "Acoustic absorption panels with textile waste" (her panels reached very good acoustic absorption performance) [5]; and Mr. Adrián Santos, the Head of Maintenance of FING, who strongly encouraged the students to look for a based-on-waste solution. After these interviews, the possibility of designing and producing absorbent panels using recyclable materials aroused: taking into account the economic and environmental advantages and disadvantages of each of the possible materials, the best option was to manufacture panels with recycled materials, specifically with paper wastes, which are one of the main wastes generated every day at FING [1].

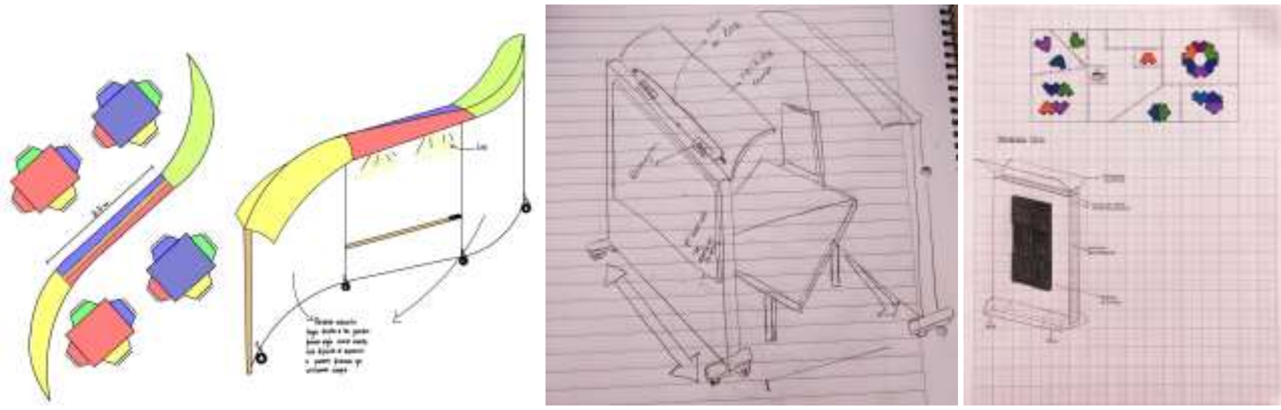

Figure 2. Some sketches for the possible solutions (From [4])

Figure 3. Models for the possible solutions (From [4])

3.3. HANDS-ON WORKSHOPS

Students and teachers worked together to achieve a set of panels to test the acoustic absorption coefficients [4]. The main input was heavyweight shredded paper, the output from a document shredder (Figure 4). The other inputs were water (hot and cold), vinyl glue, plastic fibers and sodium borate (as a preserver and anti-fire agent).

First of all, some racks were assembled, using metal frames of 0,40 m x 0,50 m, fine fabric and wire (Figure 5). After trying different compositions for the paper dough, the panels were done with paste prepared as follows [4]:

> Fill a 10 L bucket with shredded paper. Kneading permanently with hands into the paste, progressively add 2 L of hot water, 4 L of cold water, and plastic strands of about 1 cm length (all the strands of a floor cleaning broom). Continue adding paper until completing 8 L of paper dough, approximately.
>
> When the paste is soft and easy to manage, dissolve 4 tablespoons of vinyl glue in 0,5 L of hot water and add it to the paste.
>
> Continue kneading until the paste is poured into the rack. Wet the paste with some diluted sodium borate, to give it fire-retardant properties.

Figure 4. Shredded paper   Figure 5. Rack preparation with a metal frame

Then, the paste was pressed to get rid of most of the excess of water. The racks were brought to an industrial oven for a quicker drying. All the process is represented in Figure 6.

Figura 6: Making the panels

Figura 7: One finished panel

3.4. TESTS FOR ESTIMATING THE ACOUSTIC ABSORPTION COEFFICIENTS

The acoustic absorption coefficients were estimated by measuring the reverberation time of a bathroom in FING, without and with the acoustic panels (Figure 8) [5]. It is a bathroom from a block of offices. It is a small space with high reverberation capacities, due to its covering of materials with low acoustic absorption coefficients, such as tiles and concrete. A sketch and a photo of it are shown in Figure 8.

The reverberation time (T_R) was measured with a Bruel & Kjaer 2250 sound level meter, Class 1 according to Standard ISO-IEC 61672:2013, with the software for directly reading T_R. The source of sound to simulate a pink noise signal was the puncturing of a balloon. Five conditions were tested, each of them repeated three times (i.e. three balloons were punctured for each of the tests conditions, to obtain three measured values of T_R): the bathroom without panels; two panels made without adding plastic fibers; two panels made with the plastic fibers as described; the four panels together; the four panels covered by a piece of canvas [4].

Figure 8. Measuring T_R in a bathroom for testing panels absorption (without and with covering by a piece of canvas)

Then, the acoustic absorption coefficients were obtained by using Sabine's equation for relating T_R, the total absorption of the room and its volume, and the difference between the results of the tests.

$$T_R = 0{,}161 \, \frac{V}{\alpha_T S_T} \qquad (1)$$

While the panels are in the bathroom, let α_P and S_T be the panels' absorption coefficient and the panel area, respectively. Then:

$$T_R = 0{,}161 \, \frac{V}{\alpha_T (S_T - S_P) + \alpha_P S_P} \qquad (2)$$

4. RESULTS AND DISCUSSION

The values obtained for the acoustic absorption coefficients α, are presented in Table 1. They are also sketched in Figure 9. As it can be seen in Figure 9, all the tests resulted in good values for the absorption coefficients of the panels in the human voice frequencies; they are not worse than those from the acoustic materials that can be bought in Uruguay. Even if all the values were close, the best option was that with the panels covered with a piece of canvas. This option has another advantage, which is the possibility of making covers for putting the panels inside, and fasten them with velcro; the covers could be removed for washing, without the needing of substituting the acoustic panels.

Table 1. Computed acoustic absorption coefficients α, with basis on the measurements of T_R

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Without panels	0,05	0,06	0,06	0,10	0,11	0,13	0,14
Panels without plastic fibers	0,00	0,00	1,00	0,62	1,00	1,00	0,99
Panels with plastic fibers	0,00	0,00	0,82	1,00	0,74	1,00	0,99
All the panels together	0,07	0,18	0,89	1,00	0,94	1,00	1,00
All the panels covered by canvas	0,22	0,25	0,89	1,00	1,00	1,00	1,00

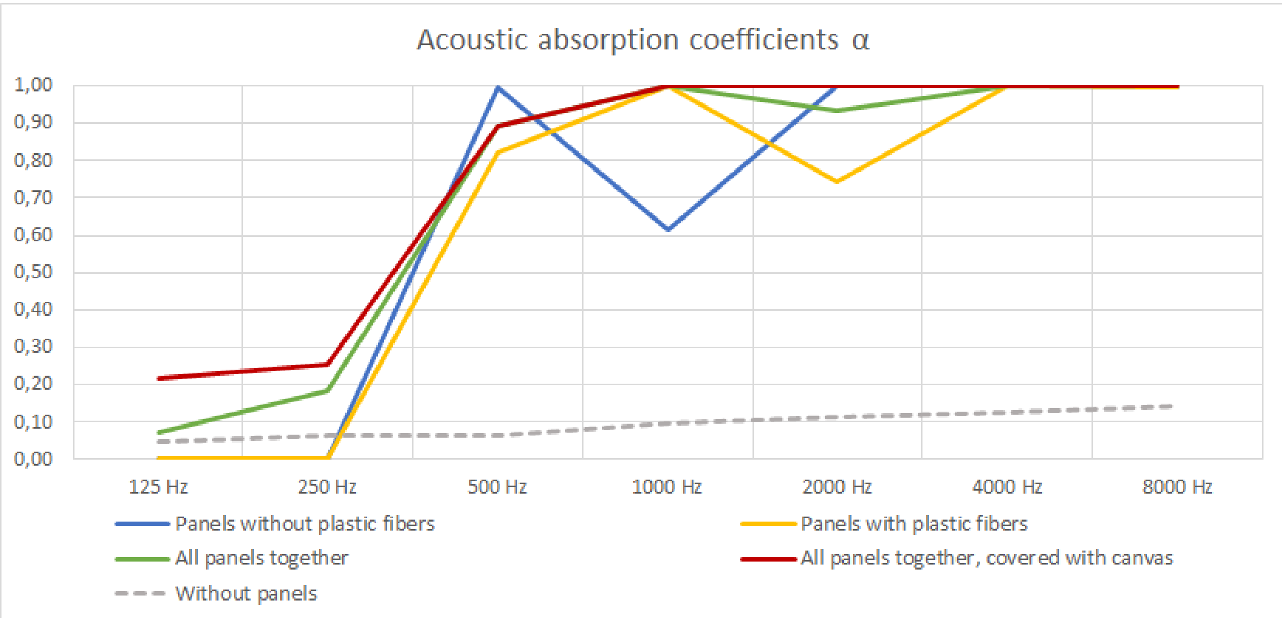

Figure 9. Acoustic absorption coefficients α

5. CONCLUSIONS

After carrying out the tests to check the acoustic absorption coefficients of the panels made with paper wastes, there is no doubt that they are a very good option for improving the acoustic conditions of the so-called 'the Green Floor', a multipurpose space used for studying at FING.

They have a good acoustic performance and they also allow entering through the theory of Circular Economy and comply with the current national regulations about waste management. The regulations establish that prevention, non-generation and minimization of waste should be promoted as the first strategy; if it is not possible, then the reuse, recycling and recovery of waste should be promoted; and as the last strategy when the previous ones are not viable, implementing the appropriate treatment and final disposal in accordance with the best practices and current regulations.

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