CAPÍTULO 4. **INNOVATIVE PROCESS OF CREATING SMALL ELEMENTS FOR BUILDING**

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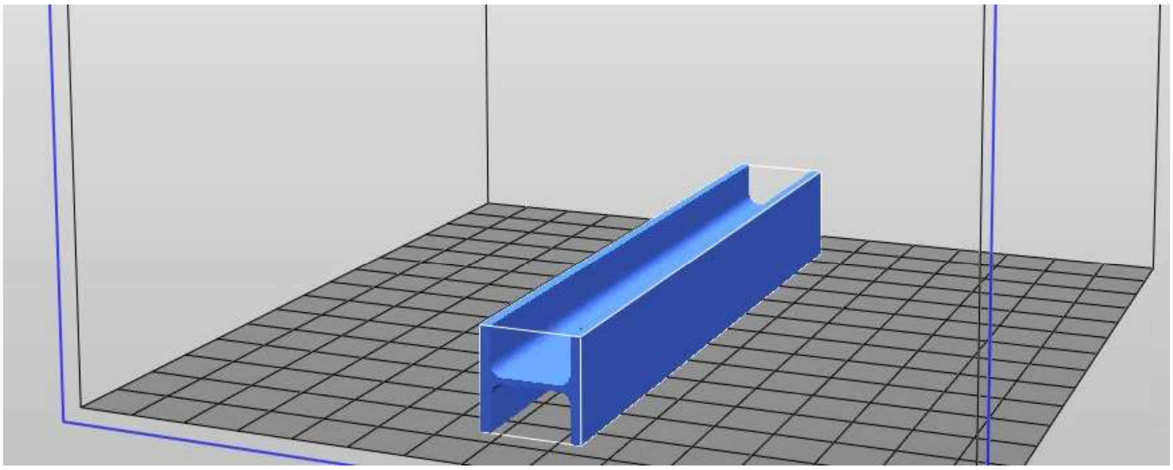
1. INTRODUCTION

It has long been assumed that innovation is the key process that drives economic growth, sustainable competitive advantages for nations and businesses, and worldwide sustainable growth (Chen, 2017; Hu & Mathews, 2005). With the recent advancement of both global and regional economies, the focus on the "Greater Challenges"1 creates a significant challenge for science, technology, and innovation (Kuhlmann & Rip, 2014). Technological and technical advances require engineers to keep up to date with the new tools, which have been developed to optimize the different processes (Pereira, Barreto, & Pazeti, 2017). With regard to engineering students, it is necessary to update the study plans so that they are competitive and have developed a series of requirements and knowledge that will be demanded of them at the beginning of their professional careers (Kroll & D. Artzi, 2011; Trust & R. W. Maloy, 2017; Clegg, Billau, & JAG. Knight, 1978).

Likewise, situations such as the one experienced recently, due to the Covid-19 pandemic, have shown that it is also necessary to adapt to situations in which teaching can be carried out remotely (Anusuya, Kumar, & Ranjith, 2021). Traditionally, carrying out laboratory practices has been one of the most difficult activities to adapt to variable situations. This project proposes a proposal to improve the quality of teaching by implementing new tools and making the possibility of moving to online or hybrid modalities more flexible (Despujol, Castañeda, & Turró, 2022). To provide students with the necessary tools to successfully develop their future tasks, it is essential to promote students reflection, learning outcomes and to realize about what the content they are learning about. So according to these objectives, active learning is an optimal tool to develop them (Prince, 2004). With the aim of adapting the study plans and implementing new tools, a didactic proposal is developed that is proposed to be implemented in the different Degrees of Industrial Engineering, as well as in Building. The proposal consists of a laboratory practice that can be implemented in subjects whose content is about casting or manufacturing processes, from a more generic point of view. With this practice, it is intended that students design, through a 3D modeling program, beams, as shown in Figure 1 to subsequently manufacture them through a sand casting process.

Figure 1: 3D modeled building element



Source: Own elaboration

To make the piece, previously, a 3D printer is used to make the model that is inserted into the sand and in this way, obtain the monde in which the metal to be melted will be poured. The material to be used is aluminum, as it is a material whose melting point is relatively low (660 °C) compared to materials normally used in construction, such as carbon steel, which has a melting point higher than twice as hot as aluminum (Sturgeon & Laird, 2000). Once the aluminum beam has been manufactured, different tests are carried out, mainly traction and compression, to check the quality of the manufactured beam.

The objective of this practice is that students can develop their skills in the use of different ICT tools, as well as in traditional processes such as sand casting for the manufacture of parts using new technologies such as 3D modeling programs or 3D printers. This brings students closer to more real work environments and closer to the real world.

2. METHODOLOGY

2.1. Objectives:

Stating the main goals of the activity is essential in any educational process. Likewise, assessments have to be linked to the learning objectives. Thus, it is fundamental to align learning the objectives, the methodology and assessment in any higher education process (Savage, Stolk, & Vanasupa, Collaborative Design of Project-based Learning Courses: How to implement a mode of learning that effectively builds skills for the global engineer, 2007). Therefore, any innovative activity must be introduced to the students a set of defined objectives and tasks (Tuunila & Pulkkinen, 2015; Savage, The Role of Design in Materials Science and Engineering , 2006). According to the previously stated arguments, main objectives, secondary objectives and transversal objectives are developed as follow (LIMA & al., 2015).

- Main objective: To provide students with a series of basic knowledge related to the world of structural elements manufacturing, as well as the necessary tools and equipment, and knowing their basic capabilities in terms of precision and finish.

- Secondary objectives:
  - Applied knowledge of manufacturing systems and processes
  - Metrology
  - Quality control.

- Transversal objectives: Development of engineering skills not included in the previous objectives
  - Use of cross techniques by using advance theoretical bibliography and cutting-edge techniques.
  - Application of their knowledge to their work in a professional way.
  - Development of autonomy.
  - Capacity to applicate the previous knowledge to practical cases.
  - Development of motivation to reach quality and continuous improvement.
  - Development of analysis and synthesis capacity.
  - Capacity to develop autonomous and deep learning.
  - Development of a critical attitude.
  - Capacity to use informatics competences in professional activities.

2.2. Content:

The process is based on a PBL methodology approach, and it implies the learning of mechanical engineering and building contents but also multidisciplinary contents in engineering and construction techniques. The work is developed during the semester in the form of a project carried out both, by groups or single students and supported by the teacher (Alves, y otros, 2019).

The methodology approaches to develop the design, manufacturing and testing of metal beams for construction. The project is developed in little separated tasks, such as the study and selection of one type of beam, its schematic and geometric definition and design, the creation of a 3D Computer Assisted Design (CAD) model. Additionally, students have to perform a quality control related to manufacturing process and the subsequent mechanical test. Finally, students have to prepare the corresponding professional essay in order to show the results and the associated conclusions.

During the first activity, students, separated by groups, have to select a case of study, analyze the real implementation of a beam and the associated loads. After that, students have to carry out a research process, obtaining geometrical characteristics and applications. Finally, it is required to develop the corresponding 3D model of the real standard construction beams and prepare a 3D printer machine to create a real model based on the CAD one.

Second Activity consists on the realization of a real beam on the bases of previously manufactured model. The manufacturing process is performed as a sand casting process. Performing this activity requires to create the corresponding mold by compacting the sand around the model. Meanwhile, it is convenient to melt the metal in order to optimize time. Once all the previous procedures are finished, metal have to be pour through the sprue. When metal is finally cold, the beam have to be withdraw from the sand. Cleaning and preparing for the final activity is the last task to carry out during this activity.

The final activity to be carried out in the laboratory correspond to the analysis and test of the manufactured beams. Students start by measuring, photographing and checking by non-destructive test the quality of the beam. On completion of the previous activity, a traction and compression test are performed. Obviously, each beam can be used for one single destructive test, so, each group of students is requested to share their information with another group.

To complete the design project, students are requested to summarize the gathered information related to the manufacturing process, a quality control report and a mechanical properties report. All of them as a professional simulation.

2.3. Format.

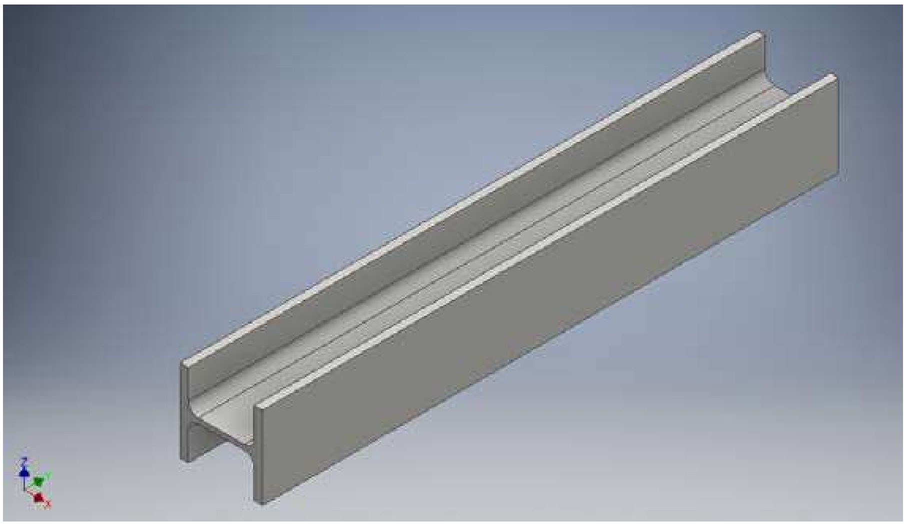
This activity has been designed as a simulation of realistic manufacturing process and its subsequent quality control. In the present case of study, students are requested to fulfill a complete real report about the process and the results.

The content and format of a real technical report is not the main or secondary objective of this project. Notwithstanding, by implementing this PBL, the aim is to develop the required cross skills that students will need in their real professional career.

3. RESULTS

First activity develops as expected. A 3D CAD model is shown in Figure 2. This task does not involves such a difficult task for students; all 3D models are correctly created respecting all dimensions.

Figure 1: Bean 3D model.



Source: Own elaboration

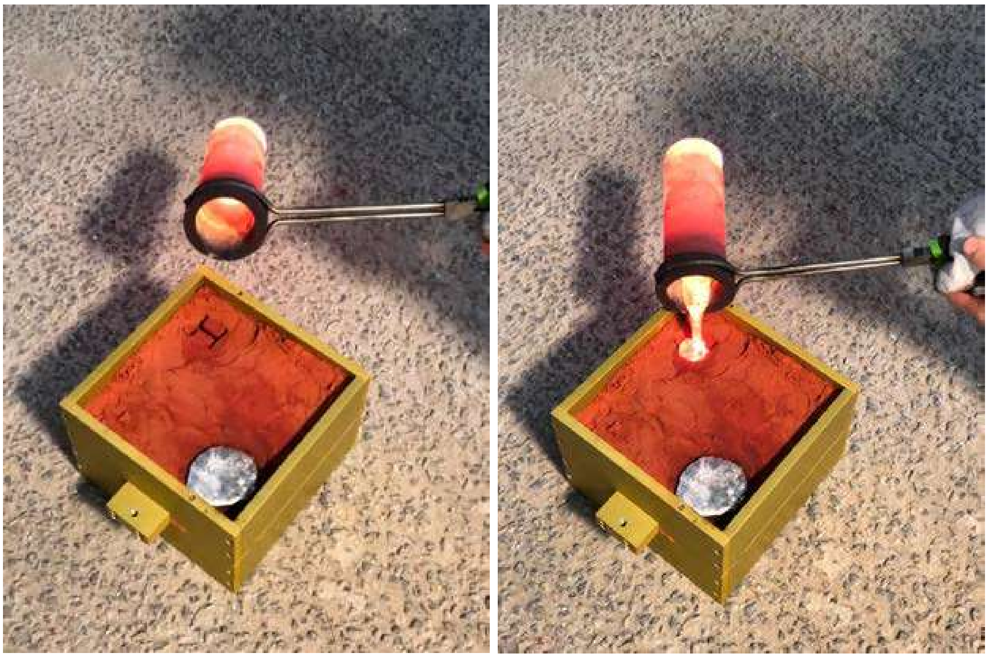
In addition, during the second activity, manual activities mean a trouble. It is necessary to repeat the process of introducing the model in the sand several times due to different issues while manipulating and removing the 3D model. It meant even to repeat and re compact the sand.

Pouring melted metal is a dangerous task. Thus to perform the process, it is essential to use all the necessary protective elements like heat protection gloves. In order to prevent possible injuries or issues caused by incorrect handling of the warm crucible, this activity is performed by the professor. The process of pouring can be observe in Figure 3. Current thermographic cameras can be viewed from remote devices as shown in Figure 2, allowing visualization of the activity to be carried out from an augmented reality system (Haglund, Jeppsson, Hedberg, & Schönborn, 2015; Kubsch, Nordine, & Hadinek, 2017). Carrying out the practice in person implements the use of different tools, but the main difference lies in the use of thermographic cameras to complement the casting processes, being able to control the casting and cooling temperatures. It is in the case of online activities that this tool comes into play, since it allows monitoring using an augmented reality model.

Figure 2: Remote access thermal camera vision

Source: Own elaboration

Figure 3: Aluminum pouring into sand mold



Source: Own elaboration

After waiting the calculated time, once all the pieces finally cold down and get solidified, students proceed to remove them from the sand molds. After cleaning properly, students proceed to perform the inspection. During this part of the activity students, detect main imperfections in the casted pieces. Mean imperfections are related to the form of the model, such as irregularities and cracks cause during solidification stage of the process. In Figure 4, it is possible to observe one of final models.

Figure 4: Manufactured bean

Source: Own elaboration

Once all the beams are cold and ready to be manipulated, students have to perform a quality control. The best ones (these which does not show critical irregularities, as cranks or a not correct shape) are selected to be used for the second activity included in this project. The ones, which does not fulfill these requirements, will be used as a raw material to melt during the next time this activity will take place. The final stage of the practical activity correspond to the development of a technical report. The summary should contain the corresponding information related to the manufacturing specifications and quality control results.

Students make the different models through the use of CAD tools (Koh & et al, 2010). Once the models are finished, they send the files, and it is in the laboratory where the staff in charge there print them using a 3D printer. Students can follow the practice through the augmented reality system.

Through the following survey, Table 1, the evaluation parameters for these designed experiences are developed. Several parameters are considered. This include concepts taught, the application of tools, the methodology, the challenges encountered, the and the implementation level of this experience. Each parameters is evaluated by using a rating, where, 1 point corresponds to the higher disagreement until the higher agreement, evaluated with 5 points.

Table 1: Opinion questionnaire

Evaluation parameters				
1. Previous knowledge has helped complete the experience.				
2. The knowledge taught is complex.				
3. I have understood the operation through observation in the laboratory.				
4. The software used is user-friendly and intuitive.				
5. The use of a thermal camera vision has helped to better visualize and understand the process.				
6. The use of software and Augmented Reality has helped move from theory to practice.				
7. I have increased my knowledge in foundry and casting.				
8. The knowledge learned has real utility.				
9. The teaching has been enough to overcome the tasks				
10. The use of software have helped to improve the virtual teaching				
11. I would like to continue learning and using about different software and Augmented Reality during engineering training.				
12. I am satisfied with this experience				
Rating				
Highly disagree	**Disagree**	**Neutral**	**Agree**	**Highly agree**
1	2	3	4	5

Souce: Own elaboration

4. CONCLUSIONS

The objective of this paper is to present, analyze and discuss the contents, integration and results of the applied methodology in order to improve manufacturing knowledge in engineering and building technologies students. The realization of the activity and the analyzed if the obtained results allow to state the bellow conclusions.

- Undergraduates appreciate the increase of the amount of real cases activities.
- A better understanding of theoretical knowledge requires to put into practice the previous knowledge.
- Students contact for the first time with building elements.
- Engineering students develop digital skills towards 3D design tools.

This activity have been design from its origin to be carried both in person and on line. According to the own nature of the activity, results are based on the opinion collected from students who answered the questionnaire shown in Table 1. Pooled data from questionnaires are represented in Table 2.

Table 2: Opinion average evaluation

Evaluation parameters	Rating
1. Previous knowledge has helped complete the experience.	4.1
2. The knowledge taught is complex.	2.2
3. I have understood the operation through observation in the laboratory.	4.5
4. The software used is user-friendly and intuitive.	3.2
5. The use of a thermal camera vision has helped to better visualize and understand the process.	4.7
6. The use of software and Augmented Reality has helped move from theory to practice.	4.8
7. I have increased my knowledge in foundry and casting.	3.9
8. The knowledge learned has real utility.	4.6
9. The teaching has been enough to overcome the tasks	3.7
10. The use of software have helped to improve the virtual teaching	4.1
11. I would like to continue learning and using about different software and Augmented Reality during engineering training.	4.2
12. I am satisfied with this experience	3.4

Souce: Own elaboration

Through the results obtained in Table 2, a series of very important conclusions can be analyzed with a view to the implementation and application of this experience to methodologies based on similar technologies. It is verified that the students value the knowledge imparted prior to the experience in a positive way, despite perceiving a certain complexity in it. The visualization of the technological elements used during the experience have made it easier for them to better understand its application. They positively value the use of visual thermal detection means, and with this they continue to increase their knowledge applied to metal casting techniques. They perceive a great application to the industry of the developed methodology, they specifically value the use of applied digital technologies and conclude that they would like to continue training in these skills throughout their training and the future exercise of their profession as engineers.

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