Designing for the Environment: an Undergraduate Case Study Supported by Global Collaborative Design

Iván Esparragoza, J. Alejandro Betancur, and Carlos Rodríguez

Abstract—Global collaborative design is a common practice nowadays due to the international nature and business scope of many corporations. Therefore, it is critical to educate future engineers with the knowledge and skills to succeed in the now common multinational settings. This paper describes an international collaborative learning experience among students from different institutions in the Americas through a multinational design project at an undergraduate level. The case study presented here refers to the conceptual design of an automatic machine to sort plastic bottles and aluminum cans to be used in different locations including malls, shopping centers, office buildings, and academic institutions among others. Global collaborative design imposes problems in terms of communication and information management; this project presents from an undergraduate case study, a methodological synthesis from which these problems were satisfactorily resolved, illustrating how a typical design methodology can be implemented in multinational projects, and how the participation of students in this kind of practice can contribute to gain knowledge in the global design process and in the development of professional skills such as teamwork, leadership, communication, and global awareness. The collaborative concepts involved in the development of this project were specially adapted from several cases of international cooperation set out in the automobile industry, where the mutual aid generated between the companies involved, enables the development and expansion of new technologies; therefore, the collaborative structure of this project has a special potential for implementation not only in academia, but also in enterprises with international projection and implicated in the management of collaborative-based projects.

Keywords—design concept, collaborative project, collaborative design, global design.

I. Introduction

Students and professionals are often involved with problems that could be better understood and solved by collaborative work. Actually, there is a global trend to develop and use collaborative design methods to find better and faster solutions to design challenges. These collaborative methods describe the design process adopted and all the steps of the collaborative learning generated [1, 2]. The main idea of this tendency is to make it possible for a team to obtain better results working with other groups, using structured collaborative methods and taking full advantage of the existing technological means to make the cooperation and communication more efficient between them. In fact, there have been a lot of studies in many areas of education and research that describe several ways to improve successfully the interaction among team groups [2, 3]; however, there is much more to show and explain in relation with the methods and ways that collaborative design can solve problems. As a result, this international experience under the global collaborative design is used not only to prepare future engineers for collaborative teamwork, but also to better understand the interaction among teams, the use of technology for communication, the flow of information, and the decision making process.

The global collaborative design is a symbiotic practice for all persons participating in the project [3], specially for students if they have the opportunity to work on the arrangement and structure of the project (planning process) and on the execution of the project, including multiple tasks and cooperative activities (participation process). Both are important learning experiences beyond the pure engineering design process. The planning process is critical in helping students understand the scope of the project by identifying the tasks to be done, determining the resources needed, and scheduling the activities to complete the project [4]. On the other hand, the participation process is significant in allowing the students to be aware of the world, understand other cultures, use technology tools, and develop teamwork and communication skills in order to improve their cooperation. This last factor is mentioned in other similar projects developed previously [5, 6], where it is noticed how the cooperation stands out as the main instrument of a team to participate in the national and international projects [7, 8], i.e., one of the collaborative design tasks is to make personal relationships stronger [9].

Collaborative design projects can be developed in academic or occupational environments; this is the first consideration when the collaborative project is going to be developed [10]. If the project is developed in an academic setting the emphasis is expected in the project process. Although, the final

Ivan Esparragoza is with the Department of Engineering, Penn State University – Brandywine, Media, PA USA (e-mail: iee1@ psu.edu).

J. Alejandro Betancur is with the Department of Physics, EAFIT University, Medellín, Colombia, Carrera 49 N° 7 Sur - 50 (e-mail: jbetan30@eafit.edu.co).

Carlos Rodríguez is with the Department of Production Engineering, EAFIT University, Medellín, Colombia, Carrera 49 N° 7 Sur - 50 (e-mail: carodri@eafit.edu.co).

conceptual design is the main result that collaborative teams are looking for, in this environment the ultimate goal is to support the learning process of the students. On the other hand, in an occupational environment a feasible solution is sought out according to a financial investment; however, in this kind of project if an enterprise is focused completely on a precise or tangible result, it could be ignoring that the social and technical achievements of their professionals during the collaborative experience are part of the enterprise gain that, although it is not a tangible result, could return all kind of remunerations to the company [11].

The flow of information and the interaction among team members are critical issues in a collaborative environment. Figure 1 shows a schematic diagram of the dynamic of interaction used in the collaborative project, where each group (circles) generates an idea (dots) and later, during periodical meetings, ideas and feedbacks are exchanged during the design process [12]. This is how our interaction protocol allows increasing and decreasing the value of the ideas generated; furthermore, is noticed how the team mates boost their attitudes, responsibilities and skills.

For this collaborative project the "Pahl and Beitz" design methodology was chosen as shown on Figure 2 [13], because it gives students many patterns to build up each phase and steps associated with the design process; moreover, this methodology allows us to develop the collaborative project using online collaborative tools [14] that can be used (specially in this kind of experiences) to plan the project, complete the tasks, and exchange ideas and documents (overcoming communication difficulties) throughout all the design steps; however, it is possible to use any other design methodology (descriptive, prescriptive, cognitive, etc), even non-sequential design methodologies, which try to show design like a complex interaction between the people involved inside a common environment , like a variable process that can not be predicted [15, 16]. In each case, the collaborative environment and interaction approach are adapted to create the synergy with the design methodology used.

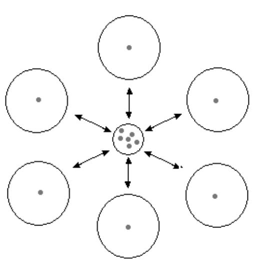


Figure 1. Schematic system depiction of group cooperation.

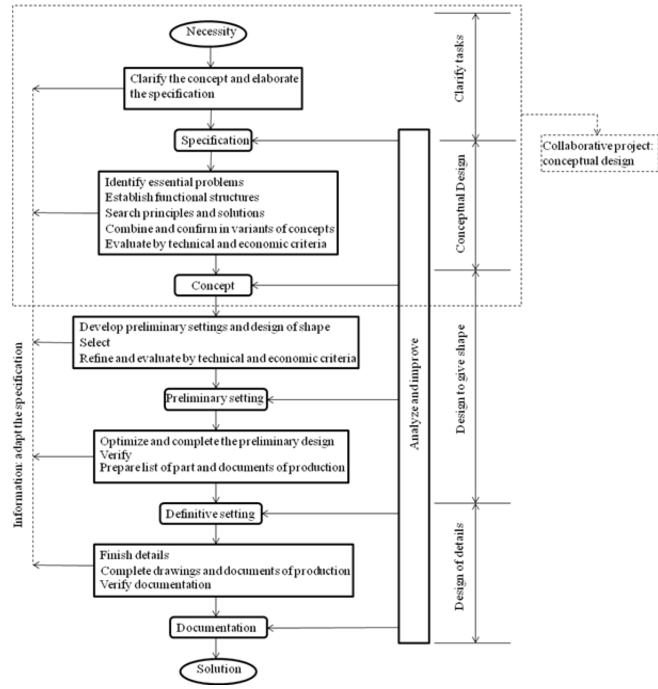


Figure 2. Pahl and Beitz methodology.

A deeper description about the above system is showed on Figure 3, which allows seeing how the ideas (all the dots) of group mates (each circular system) are related; this graph shows how ideas generated by team members are transmitted to the other partners (routed semicircles). Analogous to the Boyle diagram logic, the ideas that are not common between any couple of members are developed by each member individually. Some of these ideas (gray dots) are discarded because they have no potential value to contribute to reach the purpose, have kind of contradiction, or simply are no commented. The other ideas (black points) become more developed and create links between them; therefore, it is possible to get them linked to other ideas of the same sort as it can be seen on Figure 3(a). Here in particular, three kinds of these ideas are generated and evaluated, and if it is necessary some characteristics will be suppressed, as shown on Figure 3(b), to create a final concept as the one shown on Figure 3(c).

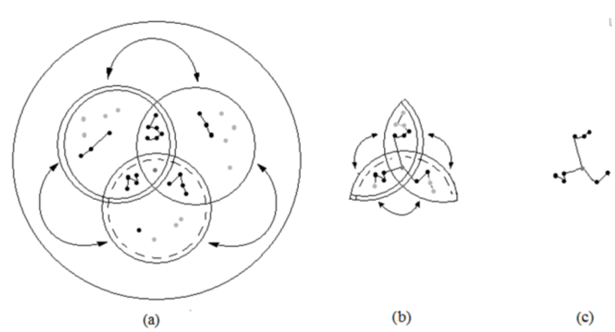


Figure 3.

(a) Schematic system depiction inside the group.
(b) System detail inside the group.
(c) Final concept.

When a collaborative project is developed it is difficult to talk only about one result. There is always a direct result which is the principal objective that the team wants to obtain, and many indirect results that cover all technical and social aspects that the experience leaves in their developers and practitioners [16]. Consequently, a collaborative project is an excellent learning experience for the students. This rich practice allows the participants to gain knowledge in the solution of open ended problems, foster creativity and innovation in engineering, and promotes global awareness, cultural diversity, and teamwork communication skills. Besides that, exposes the students to the use of technology tools for multinational collaboration. Winograd (1995) comments that "*the design cycle does not start and end with the product. It co-evolves in an environment in which new tools lead to new practices, creating problems and possibilities for new innovations*".

This paper describes a collaborative exercise that contributes to understanding the general collaborative project dynamic, explaining and analyzing a particular case carried out between students from different universities in the Americas, exemplifying its development through depictions that clarify and explain the project process. This work is presented in two parts. The first part is related to the structure of the project, and the second part is focused on the results of the project; this is done with the intention of putting the collaborative project in perspective, giving a clearer overview between the planning and execution phases, and the interactions and results generated during the solution of the design task here proposed.

All students involved in this practice agree that independently of the technical results obtained during the collaborative experience; this kind of practice taught them fundamental professional competencies related to the global environment. This is considered a great gain, since these skills are not usually learned in a traditional lecture in a classroom.

II. Project Structure

The project considered for this case study involves the design of a sorting machine for recycling aluminum cans and plastic bottles. The sorting machine should be capable of receiving in any order and position plastic bottles and aluminum cans and arranges them depending on the material for proper distribution to recycling companies. The sorting machine is to be used in different settings including shopping malls, office buildings, academic institutions and other public areas.

There are different types of collaborative projects that can be adopted as described by Jenkinson et al, [17]. The complexity and resources that are necessary to implement them vary from simple and low cost projects to more complex and expensive ones. Usually, the simple and less expensive project consists of a case study where the students just report the final result to their international partners. In this type of project, minimum interaction is required and is usually a one-time, in class experience. In contrast, the international projects known as "integrated teams" require further interaction between students, since they work together in multinational teams. These projects are usually for a long term and demand high level of commitment from students and staff. The criteria to select the appropriate type and level of collaboration depends on the general objectives, rank and content of the course in which the project will be offered, the level of commitment of faculty and students, and the resources available.

A. *Collaborative network*

The project structure selected for the international collaboration reported in this paper is the parallel design project in which the teams in each country work independently on the same design proposal but they have to share information and discuss ideas with their international partners to enrich the final solution.

The case reported here summarizes the interaction between the teams from Penn State Brandywine in Pennsylvania, USA, Universidad EAFIT in Medellin, Colombia, Universidad Autónoma de Occidente in Cali, Colombia, Universidad APEC and Pontificia Universidad Católica Madre y Maestra both in Santo Domingo, Dominican Republic. The collaborative network is shown on Figure 4, so, each team has at least one international partner to discuss the project and share ideas through scheduled audio-video conferences, email exchange, and other tools available for the project. The audio-video digital conferences were the principal way of interaction between the teams and the e-mail was the principal tool to share information. It was noticed how the different teams predisposed by their diverse backgrounds and experiences, used different digital tools during the project, creating challenges for communicating and sharing information. Consequently, it was decided to work under a common digital platform to facilitate the interaction among the teams.

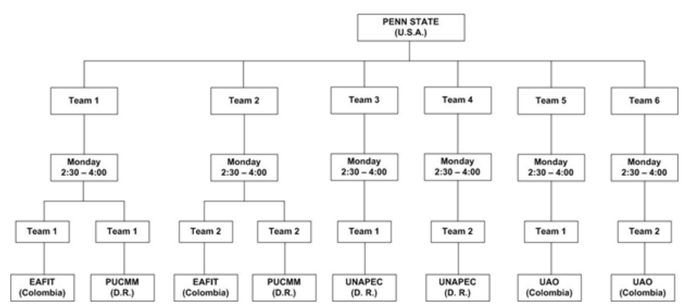


Figure 4. Collaborative network.

Formal and informal tools for interaction were used by the teams. Formal tools are those considered fundamental for managing the project and for creating a professional environment [18, 19, 20]. Adobe Connect ® for audio-video conferences, Collaber ® for project management, sharing files and repositories, and e-mail accounts for messages and sharing short information, are considered formal tools in this project. Informal tools are those considered important to build personal relationship among the participants and overcome the difficulties of working with partners geographically disperse with no physical interaction.

The use of informal tools for communication inside the groups was somehow extensive. For example, it was observed that each team used informal online tools like Messenger ®

and Facebook ®, to shear information and ideas quickly about the project, and they used face- to-face meetings to clarify concepts. On the other hand, they used formal tools like Adobe Connect ® platform for two hours scheduled meetings during the collaboration period, to exchange ideas and talk about their goals, problems and suggestions, and developing personal dynamics that supported the design process adopted by each group. The reason why it was chosen this software platform is the integrated support for learning and project presentations, in this sense, the platform can be consider more than just a communicative tool.

B. Collaborative tools

Firstly, all teams proceeded to conduct a state of the art, consolidating the most important information, this with the aim to analyze if the generated solutions might be raised (according to the context established in the collaborative project) or not.

Secondly, each team (emphasizing in the strong relationship concerning to the machine requirements, solution options and potential users) began their data collection in order to compare and complement the information recollected.

Using data collected, the teams proceeded to accumulate statistics from potential users, which were ranked by age, social class, recycling habits, aesthetic trends, among others. Comparing the surveys questions between them, it was evident that the surveys disagreed, due to the culture context where they were purposed; nevertheless, there were not big differences between the survey final results.

Thirdly, design specifications were created as a starting point for generating alternatives, at this stage in the designing process, each team pointed toward a common objective. The way the design alternatives were developed in the majority of teams was graphically, unlike some teams developed design alternatives writing; combining both forms of design, great clarity in the concepts generated was obtained, and matching those kinds of alternatives, the identification of new ideas was possible.

Finally, as a result of this process each team evaluated their ideas and proposed a final solution to the assignment, which was developed digitally using CAD (Computer-Aided Design) Software.

Here below, on Figure 5 we depict a configuration that represents the stages of interaction across the project; this Figure shows the established relation between individual and collaborative work with the external influence, and illustrates how ideally a collaborative project should be oriented by an authority character that acts like an ideas moderator, in which converges the feedbacks of the team. All this gives a concept of how a collaborative project could be oriented through a particular objective.

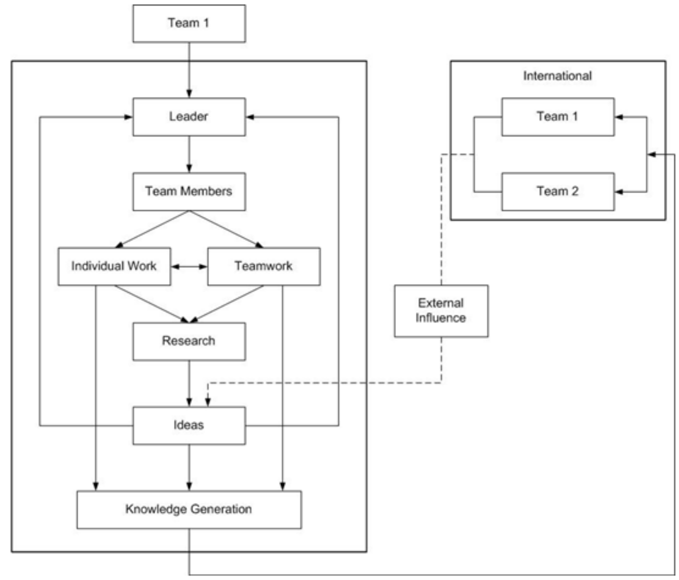


Figure 5. Project development process.

C. Collaborative design approach

Latin America countries are interested in fostering recycling programs to reduce energy usage and environmental contamination. Now, many places including shopping malls and academic campuses are using recycling bins for final disposal of beverage containers. Traditionally, a common bin is being used to collect all plastic bottles and aluminum cans similar to those in the US. However, small recycling companies in Latin America are only interested in the plastic or the aluminum containers and they don't have the infrastructure to sort the materials and most of them are only interested in one type of material. Therefore, there is a need to design an automatic machine capable of sorting any combination of common beverage plastic bottles and aluminum cans, so the sorted materials can go to different recycling companies.

Because of the efforts carried out by organizations worldwide in the field of recycling, the idea of implementing recycle programs around the world is spreading quickly. The way each country is embracing this initiative varies depending on the level of knowledge of the recycling programs and the resources available to implement them. The first challenge for the multinational design teams is to understand the characteristics of the countries participating in the project, the nature of the users and the stakeholders' requirements. The next step for the design team is to describe the main functions and sub-functions desired in the apparatus and establish the design specifications. Based on the knowledge gained about the design project, the creative phase is reached, where innovative design alternatives are generated, discussed and synthesized. The selection phase allows the team to evaluate the alternative solution and select the best one among a set of options. The final stage of the concept development for this project consists of the detailed description and 3D sketches of the proposed solution for the design problem. Table 1 presents the design steps followed in the collaborative project, indicating the stages where international interaction took place.

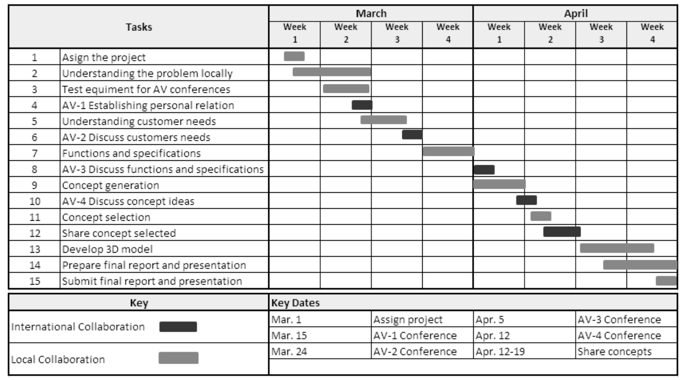
Table 1. Collaborative Global Design Steps.

Phase	Personal proceedings	Internal interaction (each team)	International interaction
1	Student commitment.	To depict the statement for this project.	No apply.
2	Perception of the design task: where the student analyze the problem.	No apply.	All the teams create friendly relations with the teams from other universities: this is necessary in order to work and communicate in a more comfortable way.
3	Identification and definition of the design task: where the student identify which problems can be solved according to our objectives.	The team mates create a list of design specifications according to the statement mentioned above in the first international interaction.	All the teams compare the list of design specifications with the list of the other teams and create common items.
4	Proposal to solve the problem: where the student look for possible solutions and alternatives, registering advantages, advances found during the process.	The team mates create a list of ideas that would satisfy the needs.	All the teams compare their list of ideas with the lists of the other teams, in order to create common items.
5	Deduction of consequences: where the student conclude about the work done.	The team mates develop a decision method to select the best concept design.	All the teams share the concept with the other teams, giving a proper description about it.
6	Verification of the consequences through actions (feedback): where the student establish how the application of concepts developed through the project can satisfy a specific goal.	The team mates create drawings of your apparatus with sketches and 3D models.	All the teams share a presentation about the complete idea, indicating conclusions, learning and references.

D. Chronogram of the project

The chronogram of activities including the design steps is shown on Table 2. The collaborative design project was structured to last eight weeks where the mandatory international interaction was required to last five weeks for the exchange and discussion of information. Teams were allowed to interact beyond the minimum required period as they considered appropriate

Table 2. Chronogram of activities for the collaborative project



E. Dynamics Interaction

This collaborative experience was oriented through the direction of the interaction of its participants by a responsible teacher, whose work guidelines is listed below on Table 3, based on these guidelines was possible to ensure the perfect synchronization between the development processes of the teams groups involved in the experience.

Table 3. Dynamic interaction of each team group.

1. To create a statement for our country
1.a. To develop meetings with the professor in charge of the group, in order to discuss about important dates, restrictions, workflow, options, etc.
1.b. To develop meetings with other team groups involved in the collaborative experience.
1.c. To develop a survey to establish the perception of people about this kind of product.
2. To create a list of design specifications
2.a. To collect all kind of information that enables the implementation of the project.
2.b. To create a first approximation to the product design specifications
2.c. To expose the specifications of the item 2.b. to the other team groups and analyze the observations of them.
2.d. To make changes and corrections to the specifics of the item 2.c.
2.e. To propose a list of common specifications for all the team groups, considering all steps of the numeral 2.
2.f. To apply the items 2.c and 2.d to the items 2.e.
2.g. To expose again the list of specifications to the other team groups.
3. To create a final list of specifications that would satisfy the user needs
3.a. To design a general choice of product performance based on the final list of product design specifications.
3.b. To expose the option of functioning indicated in the item 3.a. to the other team groups and analyze the observations them.
3.c. To Make changes and corrections to the operation mode indicated in the item 3.b.
4. To generate concepts based on the final operating mode of the device

4.a. To evaluate concepts based on the product design specifications.
4.b. To select a definitive concept based on the evaluation made in section 4.a.
4.c. To expose the final concept to all the team groups, and analyze the concepts of them with the intention of include new features or redesigns to the own-concept.
4.d. To generate a new concept based on comments made in the item 4.c.
5. To create drawings of the final concept with sketches and 3D models
5.a. To explain in detail the final concept and the potential contributions that each group may have given to the conceptualization of the final product.
5.b. To Expose the final concept to the other team groups.
5.c. To expose the final concept to the professor in charge of the team group and to the public interested, making emphasis in the learning generated during the project.

F. Principal requirements for the product design

The product specifications considered at the beginning of the project were complemented according to the results obtained in the market research surveys (developed independently by each team work at the beginning of the project); therefore, each team built up new particular notions to develop the machine design.

Then, all teams defined what kind of information could be taken into account as a real product design specification (PDS); it was realized a classification about each team requirement to obtain common set of specifications, this classification brought information about the most important requirements for properly design the machine. An example of all the above is shown on Figure 6, where a PDS relation of some important specifications from each team are combined in order to obtain a set of common specifications.

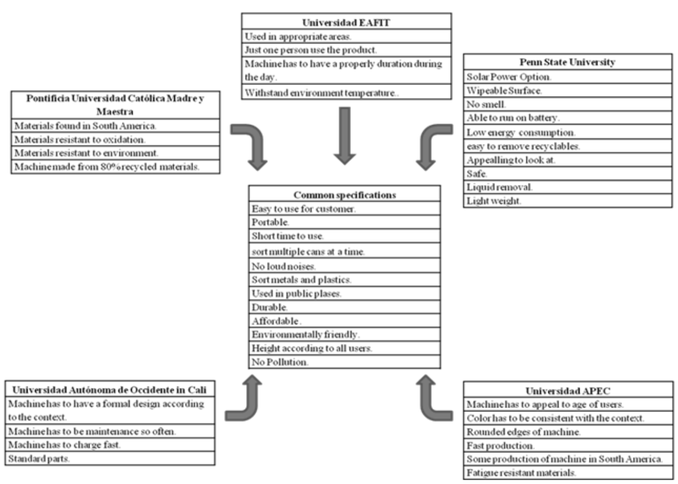


Figure 6. PDS relation.

III. RESULTS

Finally, each group defined a final concept according to all the design processes done until this stage, the final concept, Figure 7, which its functional sequence operation is explained by Figure 8, was made by one of the EAFIT teams, and it was influence directly and indirectly by almost all the teams involved in the collaborative experience. For more clarity, on Figure 9 the general functions of the product are mentioned using a schematic block diagram, which additionally represents the general operation of every concept design proposed in this collaborative project.

Figure 7. Final concept of the Universidad EAFIT.

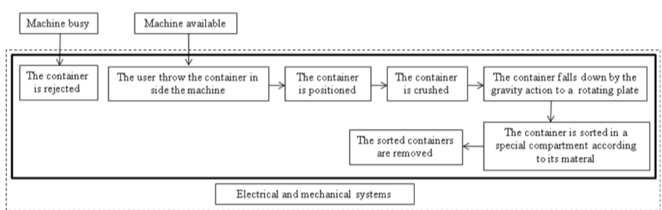


Figure 8. Operational flow.

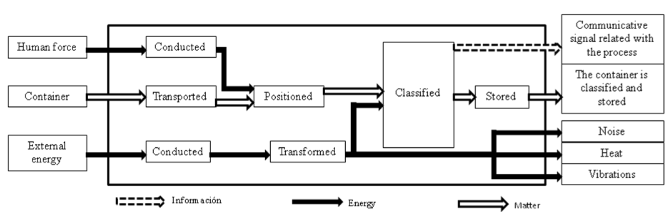


Figure 9. Schematic representation of the machine functions.

This final concept is depicted in detail here below on Table 4.

Table 4. Machine description.

Implications
1. This product only can receive one container by time.
2. The container has to be dry in their outer surfaces.
Considerations
1. On Figure 9 is showed the space for the electrical system; the user only can access this space by a key.

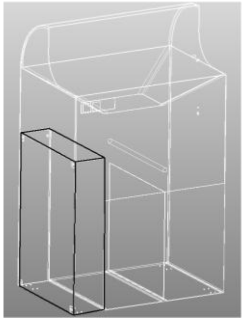


Figure 10. Space for the electrical system.

2. The product has two LED (light emission diode) green and red, which respectively indicate when the machine is sorting a container and cannot receive more products, and when the machine is able to receive a container, this idea was taken from the alternatives from Penn State university.

Figure 11. LEDS product.

3. Later the user have to pull up the machine tape to insert the container, this concept was suggested by the teams from the Universidad Autónoma de Occidente in Cali.

Figure 12. Machine tape.

4. After the product get inside into the machine, it is conducted by a channel, in order to be positioned for the next stage.

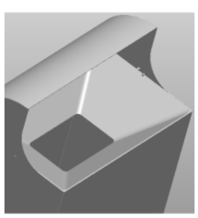


Figure 13. Channel to conduct the product.

5. Then, the container is crushed by a pressure system, when the container is completely compressed, the electrodes located in one of the plates of the pressure system become active; those electrodes have the function of send a current between two o more parts of the products, therefore if the container is made of aluminum an electric current is going to flow through the container; On the other hand, in the other plate of the pressure system there are many current sensors, which manipulate the current sensed to generate orders to the next stages, so if the container situated between the plates is made of plastic, it is going to melt a little and no currents it is going to be sensed; additionally, this sensors and electrodes can make an axial movement to guarantee that the container never paste to the plates of this system; this was inspirited by the concept design of the students from the Universidad APEC.

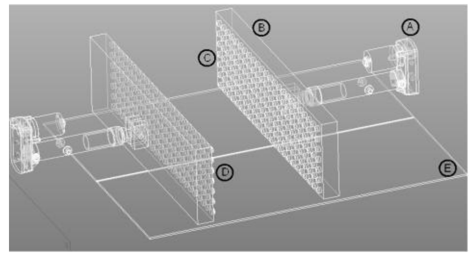


Figure 14. Pressure system.

A) Set of motor and lineal actuator.
B) Plate of the pressure system.
C) Electrodes of the plate, which move though the plate to always ensure that the container leaves the plates
D) Current sensors that move as the electrodes do.
E) Stall door.

6. Next, the pressure system is retracted and the product fall down to a rotating plate that sort the container according to a signal received by the electrical system, this system situate the container into their respective flask; this system was taken and improved of the teams from the Pontificia Universidad Católica Madre y Maestra.

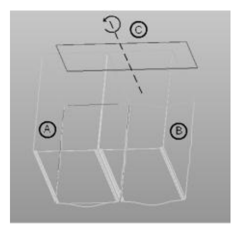


Figure 15. Flask system

A) Aluminum container.
B) Plastic container.
C) Rotating plate.

Summarizing, it was necessary to realize a complete design process to reach a goal, it was obtained a lot of technical and social results that justify all the effort, perseverance and the time spent in this collaborative experience.

IV. Conclusions

1. It was noticed that teamwork and group stimulation can be targeted toward the development of design concepts, and can suggest solutions much more focused and precise about the proposed problem.

2. We found that an advantage of the way that this project was established is the research skills enhancement of the students, because the necessity that they feel to develop the project by themselves, due to the trust that the professor give they to manage the project.
3. For a future opportunity we suggest that all the professors involved in the collaborative project make use of an independent software platform to discuss about their students opinions, with the intention of improve the learning dynamic and the communication efficiency between the teams involved in the designing process.

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Ivan E. Esparragoza is an Associate Professor of Engineering at Penn State Brandywine. His interests are in engineering design education, innovative design, global design, and global engineering education. He has introduced multinational design projects in a freshman introductory engineering design course in collaboration with institutions in Latin America and the Caribbean as part of his effort to contribute to the formation of world class engineers for the Americas. He is actively involved in the International Division of the American Society for Engineering Education and in the Latin American and Caribbean Consortium of Engineering Institution (LACCEI) as Vice-President for Research.