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Prototype of an idea to support plastic recycling, the CUBITO case

Prototipo de una idea para apoyar el reciclaje de plástico: el caso de CUBITO

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Technological Innovation: Provoke the didactic exploration of design and prototyping with an environmental perspective.

Industrial Application: Plastic Reutilization.

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Resumen

El reciclaje involucra la transformación total o parcial de un producto que ya ha cumplido su propósito en otro producto para su utilización subsecuente. Existen muchos factores que determinan el que un proyecto de reciclaje sea exitoso. Con frecuencia se pasa por alto -por ejemplo- que un producto reciclado debe ser verdaderamente útil para el siguiente usuario, más allá de ostentar la etiqueta de 'fabricado con material reciclado'. Este trabajo se enfoca en el diseño de componentes que a su vez se puedan ensamblar sin necesidad de usar accesorios adicionales de sujeción para formar una estructura cúbica. Formalmente, la intención es la de diseñar un contenedor multiusos que se pueda ensamblar por inserción y presión. Esta descripción en inglés genera el acrónimo CUBITO (Containment Utility Bin by Insertion and Tucking Operations). El prototipo de CUBITO se diseñó con el paquete Siemens NX y se creó con una impresora 3D para que se pudiera evaluar su funcionalidad, lo cual es el foco de este artículo. En el futuro, se planea que CUBITO se pueda fabricar a partir de material reciclado PET, el cual se utiliza en las botellas para transportar agua para beber. Por diseño, una de las piezas de CUBITO se podría moldear con

el material proveniente de estas botellas. Finalmente, un mensaje importante entre líneas es que con este proyecto se pudo volver a generar interés por la manufactura entre nuestros estudiantes de ingeniería industrial al atar esta actividad con un impacto ambiental positivo.

Palabras clave: Desarrollo de Prototipos, Educación en la Ingeniería, Impresión 3D, Manufactura, Reciclaje.

Abstract

Recycling entails the partial or total transformation of a product that has already served its purpose into another product for subsequent use. Successful recycling depends on many factors. An often overlooked one is that the post-recycling product needs to be truly useful for the consumer beyond its label of 'made with recycled material'. This work focused on designing components that could be assembled without the need of additional fasteners onto a cube-like structure. Formally, the intention was to design a Containment Utility Bin Through Insertion and Tucking Operations (CUBITO). The prototype of CUBITO was designed using Siemens NX computer-aided design software and it was 3D printed to test its integrity and functionality when empty as well as with different kinds of loads. This manuscript focuses on this prototyping phase. In the future, CUBITO will be built with components molded from recycled PET. An initial estimation is that one PET water bottle could be melted and molded into one piece to eventually form a CUBITO by putting the several pieces together. An important subjacent point in this work is that, throughout the years it has taken to develop, it has renewed the interest of Industrial Engineering students in manufacturing due to its ultimate goal to have a positive impact to the environment.

Keywords: Engineering Education, 3D Printing, Prototyping, Self-assemblies, Manufacturing.

I. Introduction

One of the most important and significant movements in the 21st century is environmental friendliness. Eco-friendly goods, services, and laws are those that have either reduced or negligible harm upon ecosystems or the environment. It can be argued that using less material to fabricate items -e.g. bottles- has been a constant effort in the plastics industry (see, for example Sánchez-Ocaña, et al, 2017) to positively affect profitability while also reducing waste. However, accumulated plastic waste must still find a way to be recycled, reutilized, or repurposed downstream to attenuate its impact in the environment, as exemplified in (Khurram, S. et al, 2017), and ideally -in the future- be chemically designed to be degraded naturally to complete a circular life (Keijer, et al. 2019). The magnitude of plastic waste accumulation in the planet is dramatically illustrated by the detection of large amounts of plastic in islands in recent years (Lavers, et al, 2019). Another key trend is that of multifunctionality. Single units are more often required to perform multiple functions. People want employees to be multitasking, machines to be multipurpose, and objects to have different uses, with the added benefit of being eco-friendly. Considering all these aspects, our project focuses on creating 3D printed prototypes that, in the future, can be converted into eco-friendly multi-functional artifacts. It is our belief that people would want to consider being eco-friendly as long as there is value in their products, which is why multi-functionality is paramount. It is noteworthy that the possibility of creating prototypes has now been enhanced by 3D printers, which brings along affordable opportunities to

integrate more realistic manufacturing undertakings in educational projects as it has been discussed elsewhere (Kroll and Artzy, 2011). Novel redesign of everyday items to assess their functionality has also been reinforced by 3D printing applications (Ramírez-Cecaldi, 2018) as the need for physical prototyping is a persisting engineering need (Koo, et al 2014). 3D printing, which is the most distinctive process of additive manufacturing (AM) is defined as the process of positing materials to make a three-dimensional object, usually layer upon layer as opposed to the traditional material-removing manufacturing techniques like machining (Moylan, 2014). Objects to be 3D printed can be designed using a computer-aided design (CAD) program, via a 3D scanner or by a digital camera with photogrammetry software. 3D printers have been a great strategy for prototyping because of the decrease of prices of the printers and the wide variety of printing materials available in the market (Meloni and Bertotti, 2017).

This paper focuses on the development of a 3D printed prototype. The pieces of the target prototype in this work had to be designed in a way that, when assembled, they would fit tightly and would not require any fastening devices, such as screws or glue to form a cube. That is, the aim was to create self-assemblies. The principle of this idea had been already tested by our group for a 2D planar self-assembly (Rivera, Niño, Cabrera-Ríos, 2016), so the challenge entailed its translation into a 3D structure. The prototype was decided to be box-like to be able to contain a wide variety of materials and, by doing so, remain versatile and useful. It was named: Containment Utility Bin through Insertion and Tucking Operations, which accounts for the acronym CUBITO.

It is proposed that, in the future, the pieces of CUBITO could be created using recycled PET bottles using a high production process such as injection molding. The feasibility of such undertaking has in fact been demonstrated elsewhere (Evastiev, et al, 2002).

II. Material & Equipment

In this project, the different units that form CUBITO were designed using the CAD program Siemens NX. The five distinct shapes of the units are shown in Figure 1. Polylactic acid (PLA) filament was used to 3D print these units. In particular, we used the MakerBot PLA filament with 1.75 mm in diameter. PLA is a biodegradable and bioactive thermoplastic aliphatic polyester derived from renewable resources such as cornstarch or sugarcane (www.see-gaia.com). The printer used for this project was a *MakerBot Replicator 2 3D printer* (Figure 2).

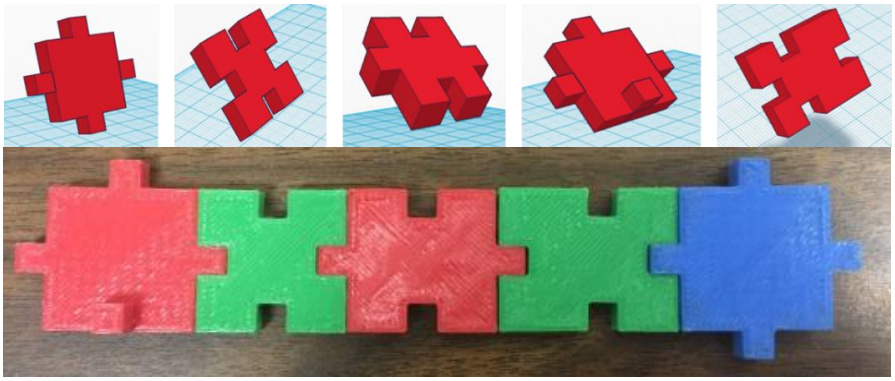


Figure 1. All five different units for the CUBITO assembly.

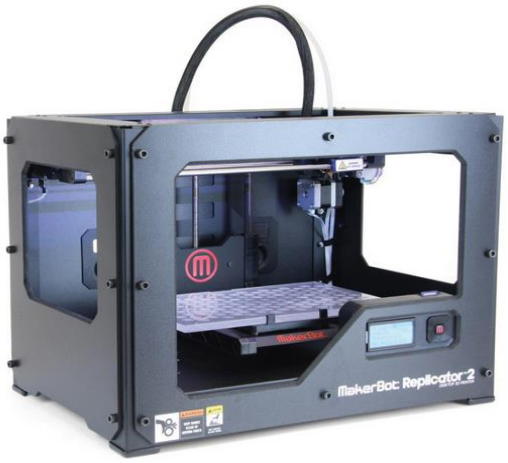


Figure 2. MakerBot Replicator 2 3D printer used to make the prototypes of CUBITO.

III. Experimental Methods

The pieces in Figure 1 were designed as variations around a square slab of 25 mm x 25 mm x 5 mm. Protuberances and cutouts, which make up said variations, were reflected using increments or decrements of 5 mm per dimension. These pieces were then 3D printed with the machine shown in Figure 2, using the manufacturer-recommended material processing conditions of 220 Celsius degrees in the nozzle, and a printing speed of 40 mm/s. Each piece took between 5 and 10 minutes to print. This first version of CUBITO served as a prototype to test the mechanical interferences between the pieces, a process that will be described in the results section. Comparing the mass of an average PET bottle (11.75 grams) and that of a single piece in this first version of CUBITO, it was calculated that between 7 to 8 pieces could be made from 1 recycled PET bottle. Figure 3 shows this first prototype from the top view.

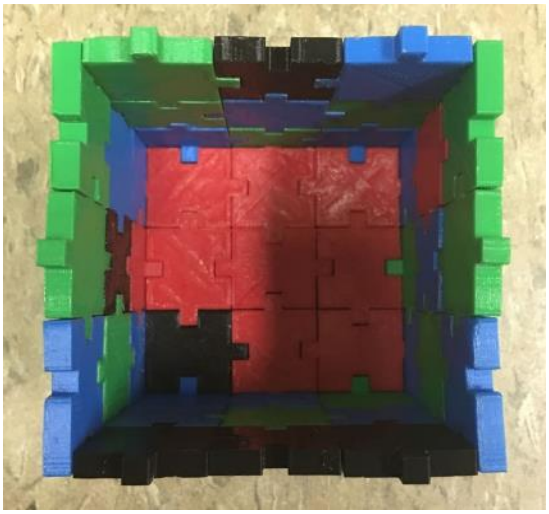


Figure 3. Top view of original prototype of CUBITO.

In terms of recycling convenience, however, it was thought necessary to aim for a ratio of 1 piece to 1 PET bottle. The pieces in this next larger version of CUBITO were then designed to have a mass equivalent to that of the average PET bottle. The resulting basic unit was a larger slab with dimensions 50 mm x 50 mm x 10 mm. Protuberances and cutouts were designed using dimensional increments or decrements of 10 mm. Each piece of this version took between 15 and 20 minutes to print. The fully assembled scaled up version is shown in Figure 4.

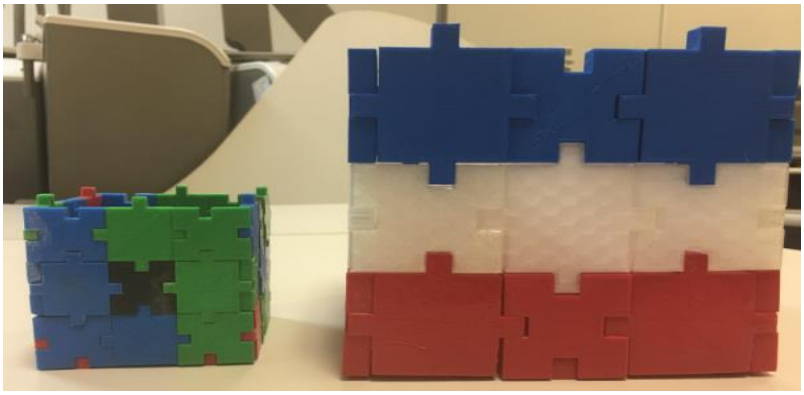


Figure 4. Comparison between the original CUBITO (left) and the scaled up CUBITO (right).

IV. Discussion and Results

The first prototype was tested by filling it up with sand. CUBITO proved to withstand 0.701 kilos (1.55 pounds) of sand without showing integrity problems, as seen in Figure 5. It was also tested to see if it was possible to hold water in it, but it leaked through the spaces between the pieces, as expected. However, CUBITO did prove to be useful as a water container if a plastic bag was placed inside it. A lid for CUBITO can be made using the same pieces used to create its floor to avoid mosquito reproduction, given the case. Among the many uses that this version of CUBITO could have, there is a possibility of using it for seeding and supporting initial growth of plants, for example.

The scaled-up CUBITO assembly proved to withstand more weight owing to its bigger size. The mechanical interference was however less tight, so the assembly could dislocate somewhat more easily (See Figure 6). Still, the scaled-up version of CUBITO could hold almost 5 kilos of sand (11 pounds) before showing integrity problems.

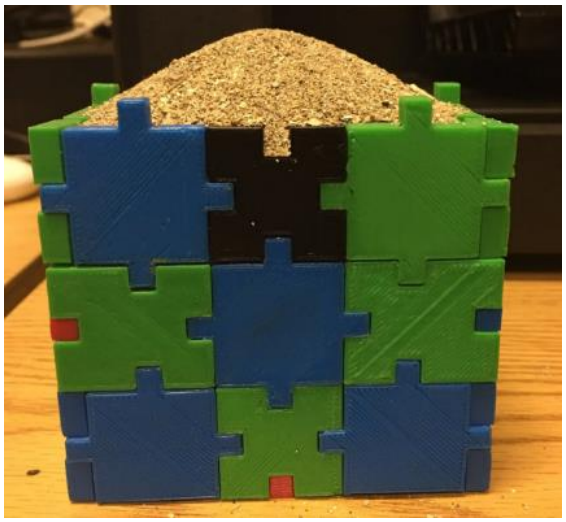


Figure 5. Original CUBITO with 701 grams of sand.

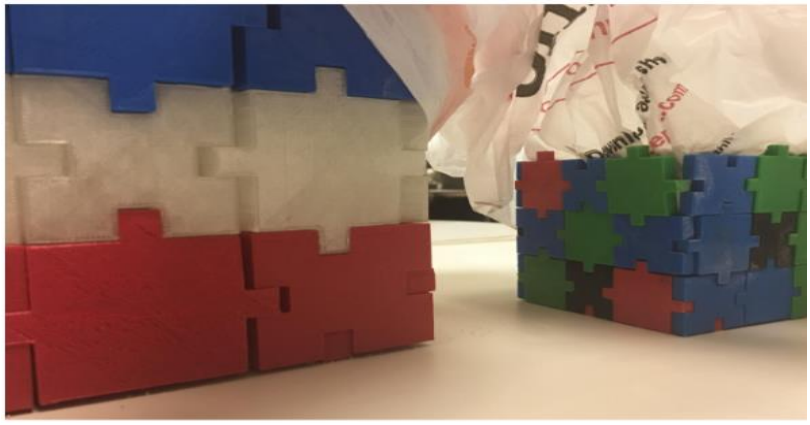


Figure 6. CUBITO and its scale-up present separation of pieces after being tested with sand.

The design and prototyping phases of CUBITO spanned four years. The coauthors in this manuscript were undergraduate students during the time they were working in this project. They passed their knowledge to other students along this time, who in turn undertook the next steps. This is important to recognize as to understand how long the implementation of similar endeavors can take in an academic setting starting from scratch. Nevertheless, a series of projects like this - grounded on an eco-friendly ultimate objective- did help on renewing the interest of our students in manufacturing.

V. Future work

Following the vision laid out in this work, a next step in this project would consist of making the transfer into a process suitable for

transforming PET bottles into CUBITO units such as injection molding (see, for example, Shritep, et al. 2011). To this end, one could consider marshaling a pilot processing line with at least the following stations in mind: (i) bottle cleaning, (ii) grinding, (iii) drying, and (iv) injection molding. Key considerations should include PET's melting point of 250 Celsius degrees and the fact that the injection molding unit should be able to fill a mold cavity at least equal to the largest piece in the scaled-up version of CUBITO. This implies that it will be necessary to fabricate independent molds for the five different units in Figure 1 to keep injection pressure and shot volume requirements to modest levels. Additional considerations must also include proper ventilation when melting PET.

VI. Conclusions

Creating the first prototype of CUBITO helped us grasp the idea of applicability and performance. Seeing that a series of interlocking pieces was feasible, a scaled up version of CUBITO was created to foster its capabilities. Uses for CUBITO can include containing small amounts of water, animal food, supporting gardening, or small-scale farming. More importantly, in the future it is envisioned that CUBITO can be created from recycled PET bottles. To this end, a pilot production line built around an injection molding machine can be considered as a next step.

Hidden in this narrative there is a more subtle message: for manufacturing to become interesting to a wider and more diverse student body, it becomes necessary to tie process and application to positive impact. In this case, alleviating environmental damage as an ultimate goal was key to attract industrial engineering students, who have somewhat diverged from a focused interest in manufacturing to move increasingly towards management and analytics. It was noticeable that the participation of female students in the consecution of this work –spanning four years- had a lot to do with this effective association of process and positive societal impact. This factor can be considered and further capitalized upon as 3D printing continues to provide a support for education in Engineering and the Sciences as discussed by (Ford and Minshall, 2019).

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