Proto-Pack: A Procedural Modular Prototyping Toolkit for Sustainable Packaging Design

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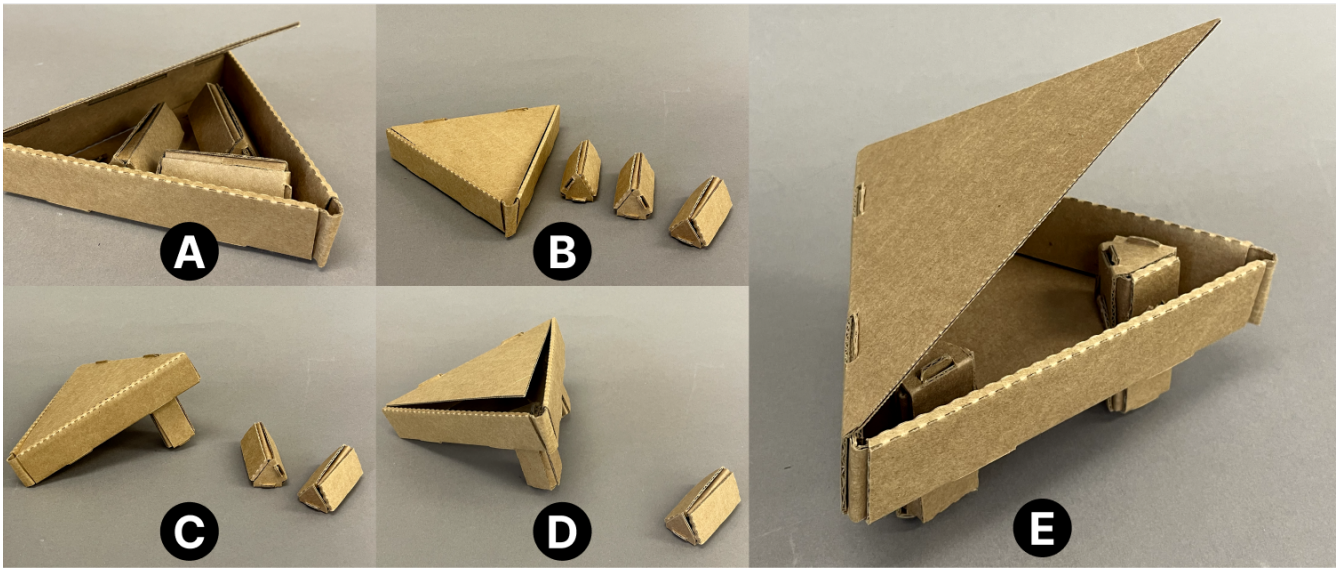

Figure 1: (A) The model can store its own legs inside the large triangle because of Proto-Packs design methods (B) The large triangle next to its smaller triangle legs (C) The large triangle with one leg inserted (D) The large triangle with two legs inserted (E) The standing piano model

ABSTRACT

Packaging design has witnessed an impressive transformation with the rise of computer-aided design (CAD) and computer numerical control (CNC) machines. Like many CNC-reliant practices, there is an inherent cost to working through the CAD-CAM workflow, especially when fit and measurement are involved. Although quick to generate prototypes, the workflow is also quick to consume materials leading to unsustainable design practices. Here, we present a more sustainable packaging design process through Proto-Pack, a CAD toolkit for procedurally generating modular, reusable, and reconfigurable packaging building blocks that increase a prototype's lifespan and utility. We show how Proto-Pack can be used to enable a sustainable workflow that reduces design footprints, supports thinking through doing, and encourages reuse of materials.

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CCS CONCEPTS

• **Human-centered computing** **Systems and tools for interaction design**; • **Applied computing** *Fine arts*.

KEYWORDS

digital fabrication, craft, design tools

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1 INTRODUCTION

We introduces Proto-Pack, a CAD toolkit for supporting a more sustainable packaging design process. Informed from a formative study using the expert-learner method, we designed Proto-Pack to mitigate the errors found in the packaging design process. The Proto-Pack design tool uses 5 design functions to procedurally generate modular, reusable, and reconfigurable packaging building blocks. We demonstrate how our modular design strategy improves physical prototyping methods by supporting thinking through doing and reduces physical design footprints. Through exemplars, we

demonstrate the utility of Proto-Pack in addressing core packaging design concerns and increasing a prototype's lifespan and utility. While Proto-Pack addresses issues within the packaging design domain, we discuss how a modular design strategy can be used to impact other digital fabrication practices such as 3D printing, CNC milling, or laser cutting. Lastly, we describe how the modular design strategy can evolve as a design process for encouraging divergent designs and mitigating design fixation encountered with templates.

1.1 Sustainability of Rapid Prototyping

Rapid prototyping assists design iteration by providing cheaper and more sustainable alternatives of visualizing and modifying models without using the real material. FaBrickation is a toolkit that worked by substituting sections of 3D printed objects with Lego bricks, lowering the time it takes to print objects while using less material [3]. Much of the design is then replaced with Lego bricks that can be removed and modified, resulting in a prototype with limitless possible combinations. Finding building blocks designs for prototypes could result in a more sustainable and engaging design process for the user.

1.2 Reducing Design Iterations

Creating physical objects from virtual models is a difficult task when taking into account the cost of developing designs, creating models, and fabricating artifacts. Recent trends have seen the development of design tools that improve design iteration by introducing new replaceable parts and using low fidelity prototypes. The FitMaker 3D editor provided users with parts that can be added onto existing models, reducing the number of iterations needed to ensure a tight fit. Many of these issues come from measurement translation issues between virtual and physical space that cannot be calculated [1]. These translation issues are prevalent when working with corrugated material, more specifically when package designers virtual designs are cut and they don't align with the real world objects they might have measured.

2 PROTO-PACK

Workflow. Instead of sketching first, Proto-Pack procedurally generates dielines from simple measurements, saving designers time. The dielines produced result in multiple components of a complete design which can be cut in sections allowing for more efficient use of space and less waste from excess material. Once the components are cut they can be constructed into the desired model or folded back down into its individual parts. The process of building, deconstructing, and re configuring a prototype makes it easier and more engaging to take risks and have variation in design. Overtime the user will fabricate more components and have access to an abundance of "building block" like parts to construct packages freely.

Most packaging designs consist of a single consolidated part with cuts, scores, and holes that fold into a single package. Rather than making a design line by line, Proto-Pack uses polygons and that can extend depending on the thickness of the material automating a tedious task. These designs are turned into .DXF files which store and transfer line type and measurement information which can

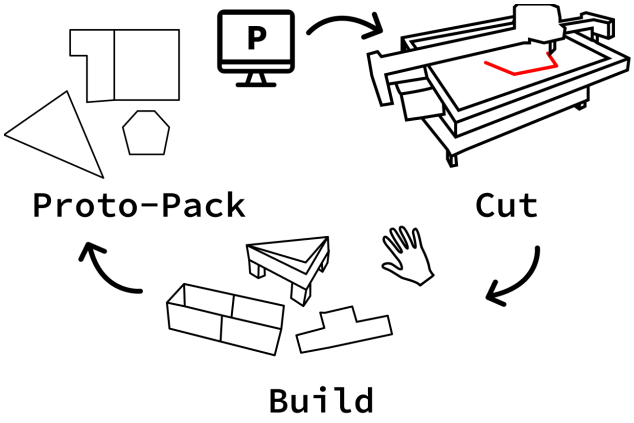

Figure 2: A more sustainable packaging design process broken into 3 steps. Designing procedurally generated dielines through Proto-Pack, simplifying the complex parts of packaging design (scoring allowances) for the user. Proto-Pack produces dielines that are broken into various parts that can be cut on cardboard sheets more efficiently saving material. Finally, once the parts are fabricated the components can be used to build up, deconstruct, and modify the package similar to building blocks

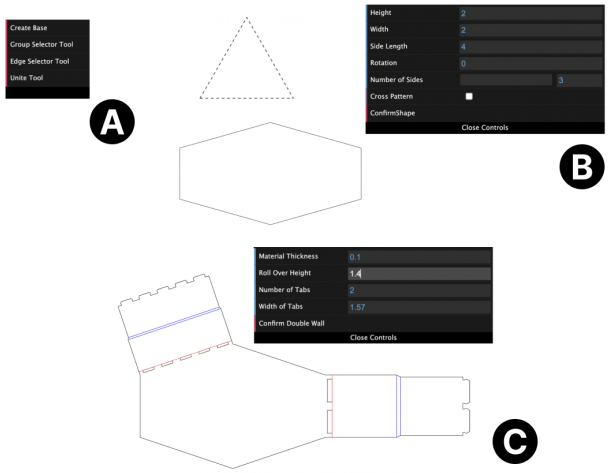

Figure 3: Proto-Packs UI, *polygon base*, and *double roll over* functions (A) Blank canvas (B) Polygon base editing (C) Double roll over editing

be used by a variety of other CAD software tools. The .DXF file of the design must then be transferred to ArtiosCAD as it is the only CAD software that can create .ACM files which are used to fabricate the designs at a digital cutting table. Finally, the design is fabricated at a digital cutting table resulting in multiple parts of a single package. A complete package can then be constructed by folding and connecting the newly cut parts together.

Proto-Pack is a vector based design tool that uses *polygon bases* to extend and connect packages (see Figure 3). Polygons can be

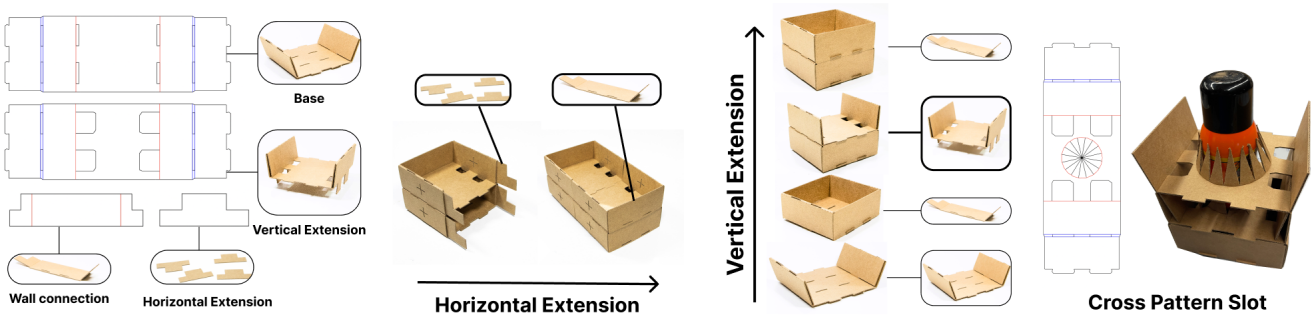

Figure 4: (left to right) Dielines created in Proto-Pack with the corresponding folded component labeled. Example of *horizontal extensions* and *wall connections* being used to expand a package horizontally. Example of *vertical extensions* being used to expand a package vertically. Example of a *cross pattern slot* holding a non-planar shape within a package

added to a blank canvas where the width, height, and number of sides can be adjusted. The polygons that are added can serve as the base of a package and a *double roll over* can be added to any side of the polygon. *Double roll over* and polygon measurements will be adjusted by *Proto-Pack* automatically to ensure each package can connect without fail. *Proto-Pack* automates tedious tasks without removing control from the user, allowing for exploration of new designs without restriction. *Proto-Pack* implements 5 main design elements to achieve it's modular design.

3 EVALUATION

The goal of our evaluation was to understand the design space of packages supported by Proto-Pack and demonstrate how Proto-Pack workflows could improve the sustainability of the design process [2].

Insights from Workflow. Using Proto-Pack we created various complex designs with precision, using simple measurements within our design space. These designs can be transferred to other CAD tools such as Adobe Illustrator and ArtiosCAD while maintaining the measurements specified in the original file; providing users with options to modify designs using tools other than Proto-Pack. Once the models were cut and manufactured we were able to utilize more space on a sheet of cardboard no matter how complex the design. Additionally, any errors from the cutting table were minimized since the error would effect a single component instead of the entire design. Once a set of components are produced we found that the lifespan and utility of the models were increased. A single set of components intended to package a simple object could be transformed into models such as a heart or mini grand piano which can serve a purpose beyond just packaging. Compared to traditional package prototypes, which serve a single purpose, and have much shorter lifespans. The lifespan of traditional package prototypes can be extended by cutting the material with a blade, but these modifications are permanent and the designer won't be able to return to the original design. Using the packages created from Proto-Pack, we could modify designs and return the its original form without cutting the previous design and creating more waste.

After working with Proto-Pack for a few weeks the number of components available to us grew. With each new design completed we could fold parts down and save them for later, then modify new packages in ways we could not have originally planned for. One of the packages we created was a mini replica of a candy display (see Figure 5 B). Using a tall hexagonal base, a tall narrow square box, and multiple hexagonal bases we constructed a modular prototype of the display. We were also able to modify our display's base to give it a more stable foundation using different triangle boxes from a different design we constructed previously (see Figure 5 C). Finally we completely transformed our display by taking the vertical build sideways and adding parts from previous designs; turning the standing candy display into a guitar shaped display (see Figure 5 D).

4 DISCUSSION

Sustainable design process. The modular packages create a system where most parts can be interchanged enabling reuse. Within a classroom environment where hundreds of design prototypes are abandoned at the end of a semester, these old projects can become usable raw material for design exploration and continue to reduce the need to cut new parts. The modular design strategy also minimizes the physical footprint of blank. Commonly sold in large sheets, cardboard stock material can become useless after a single print. The simple and compact footprint of Proto-Pack components allows more of the stock material to be used, similar to communal practices with laser cutters and acrylic and wood materials.

Understanding modular ideation. Through our process we believe the designer is much more active in the design and learning process because they create each component and build the packages as well. Designers approaching the open modular design may explore more epistemic actions to reach their goal by testing combinations that may not advance them to a package while learning more about the properties of the material and how components work together.

5 CONCLUSION

We introduced Proto-Pack into the packaging design process with the goal to support a more sustainable packaging design process. Proto-Pack can create reusable, and reconfigurable packaging building blocks that increase a prototype's lifespan by encouraging reuse, increasing utility, and using material more efficiently. We showed

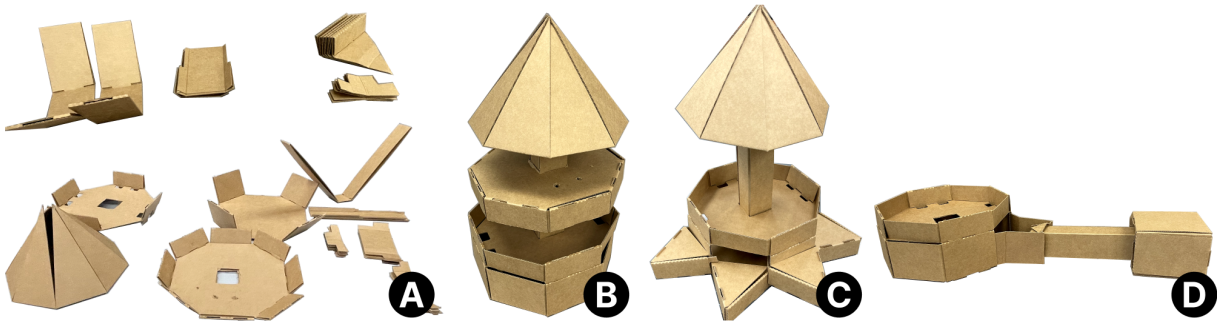

Figure 5: (left to right) a group of cardboard parts laying flat. A standing mini display for candies, constructed from the previous cardboard pieces with a hexagonal base. The previous display, with sections of the display removed and new parts added to create a newly shaped base. The previous display completely reconfigured to form the shape of a guitar

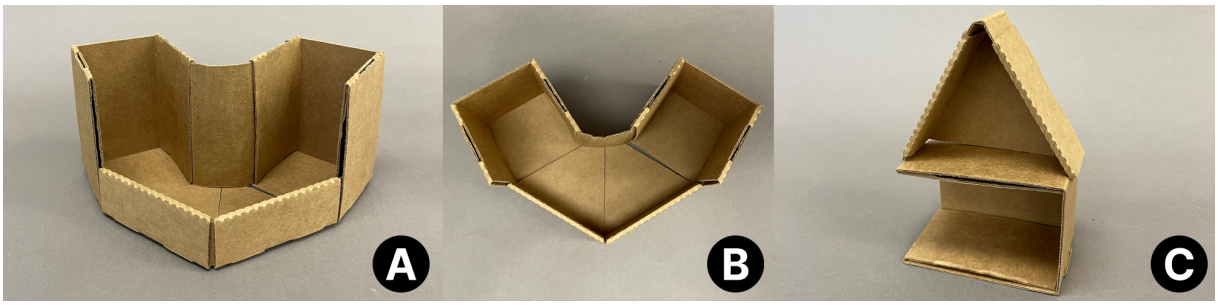

Figure 6: (A) Forward view of the heart package (B) Top view of the heart package (C) Forward view of the house package

how Proto-Pack's modular packaging building blocks could produce various package designsand how a design process that involves iteration could influence tacit knowledge and support a deeper material understanding for the user.

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