Automated Packaging Design Method for Reusability

A Major Qualifying Project Report Submitted to the Faculty of
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Abstract

Air accounts for a quarter of packaging contents being received and shipped worldwide. This project analyzes the current packaging system and proposes a new method of sustainability with a focus on customizable packaging and its reusability. Several packages of technical items were assessed in this study to determine the quantity of waste. Recording measurements of items and their packaging, the team derived a design solution to remove excess packaging waste while protecting the item through transit. Parametrized CAD templates were developed to accommodate different-sized parts and applications. A complementary flowchart was designed where the user can input product dimensions and characteristics such as fragility, temperature, and weight. The flowchart will lead the user to the appropriate packaging CAD template, which can be modified and manufactured as per needs. Various test cases with different products were used to evaluate this packaging concept with a good amount of success.

Acknowledgments

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Authorship Page

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Table of contents

List of Figures

List of Tables

1 Introduction

The Covid-19 outbreak has altered the current industry drastically. As consumers and other sectors of commerce adapt to recurring outbreaks, there has been a great demand for e-commerce shipments. Though the change in consumer behavior is to mitigate the spread, single-use packaging is also accumulating environmental waste. Sustainability is quickly finding itself at the forefront of human existence. Companies all over the globe are committing to net-zero carbon emissions in their bid to stifle climate change (*Packaging,* n.d.). This project focuses on the improvements that can be made in the packaging industry to reduce waste and improve efficiency.

Problem Statement:

The economy is built on the manufacturing, selling, and buying of goods. Transportation of these goods requires a durable, sustainable as well as an energy, and cost-efficient method of packaging, specifically, packages bought online by consumers.

Goals Statement:

A possible solution is an automated system that has a product model as an input and it will output the package design. In order to achieve this, a set of requirements must be created for the system to produce a package design with minimum waste while still protecting the product.

The goal of this project is to evaluate issues of the current packaging system and implement a packaging method that is sustainable. We achieved this goal through the following objectives:

1. Addressed the causes of environmental waste in the current packaging system
2. Developed a flowchart that meets consumers' needs as well as reduces packaging waste.

3. Designed parametrized solutions in Creo PTC of packaging designs for items of different sizes and weights.
4. Tested parametrization of designs by inputting different dimensions of items needing packaging.

The report is organized for the chapters to discuss how each objective was met. Chapter 2 provides the background on the current packaging issues and present research. Chapter 3 will discuss the methodology of designing a packaging solution. Chapter 4 provides the analysis of the curated method. Chapter 5 then provides conclusions of the project and recommendations.

2 Literature Review

Throughout our undertaking of this project, we will take a critical look at existing literature and current packaging methods.

Packaging exists in multiple subsets (Rundh, 2009). An individual product (for example an iPhone) is contained in its immediate packaging that we are familiar with. This is designed by the company and typically focuses more on the impression it has on the consumer. There is also a subset of wholesale products. This is the packaging used for products being shipped between manufacturer and retailer. Our focus is on shipping packages between the retailer and the consumer. We chose this due to the following reasons:

- Accessibility to test
- Personal recognition of waste
- Large scope for improvement
- Importance of improvement, especially after covid

2.1 Overview of packaging

Since the early 1800s, packaging designs have been evolving and increasing their functionalities after Nicolas Appert introduced the first method of preserving food by containing it in a glass jar, sealing it with wax and a cork, while remaining in boiling water (*A History of Packaging*, n.d.). Such an efficient invention for transporting goods led to the production of cardboard boxes, bubble wrap, air pillows, and packing peanuts. Each method of shipment follows the same 3C's principle within the packaging industry namely containing, caring for, and conserving the intended product. This principle can even be seen in today's time among major shipping companies such as Amazon, FedEx, and UPS. However, with such a vastly growing industry and an increasing demand for products to be shipped, there are several aspects that have been overlooked and negatively causing harm, money, and unnecessary efforts for the sellers, consumers, and environment (*A History of Packaging*, n.d.).

2.2.1 An automated packaging planning approach using machine learning

The packaging industry in the entire world is constantly increasing and obtaining new methods of transporting goods to make things more efficient for the creators of the product, but more importantly, meet customer requirements. As a result, several companies and researchers are finding new ways to adapt to every need. The article "An automated packaging planning approach using machine learning" by D. Knoll, D. Neumeier, M. Prüglmeier, and G. Reinhart, goes in-depth on their approach to diminishing and overcoming these challenges. The goal of this paper is to create an automated system in which the part's characteristics are put into machine learning. There is a two-step process in which the part's historical data and part specifications are taken into consideration so that an 84% accurate package compared to the real-world is created. That being said, the manufacturing industry has created an integrated supply chain network to deliver a continuous supply of parts that the authors mentioned needs to "enable the transport and protection of parts, protect both the parts and the environment, and enable the identification of parts"(Knoll et al., 2019).

2.2.2 Safe transportation of product

When dealing with customers' products, there is no doubt that the transportation needs to be perfect in order to properly receive the product the way it was manufactured. This relies on the packaging and more importantly, the protective materials and measures added within the process. In the article "Design and Analysis of Cushioning Packaging for Home Appliances", Gui Kun and Wang Xi talk about the issues to be overcome when designing the packing liner of a flat TV. These issues include making the liner reusable, determining how vulnerable the product is, and the impact stress of landing must be less than the maximum stress the support can withstand. In efforts to create a proper package, the creators used a finite element software known as ABAQUS to make a simulation model displaying several components of physics such as explicit dynamic theory and elastic potential energy. Throughout several experiments, they discover that the TV landing impact stress is less than the maximum stress of the liner. Furthermore, they analyze how the liner in the delivery process has better protective capabilities and can also be reused (Kun & Xi, 2017). Thus, diminishing wasted materials and utilizing more sustainable resources.

2.2.3 Specific aspects of packaging

To the average person, it may seem like packaging a product is a very simple process. However, in modern times, product packaging is a very complex choice and varies for different companies based on several internal and external factors. In Bo Rundh's article, " Packaging design: creating competitive advantage with product packaging," they go in-depth on several different factors that play a role in a product-specific type of packaging. A good example they address is environmental influences. Climate change and toxic waste has been an increasing environmental issue. That being said, several governments have set forth laws or companies choose on their own to incorporate their product with packaging that is recyclable or reusable (Rundh, 2009). Technology has also had a tremendous influence on packaging. Technology introduced laminating for new materials. Additionally, technology allowed companies to use printing as a form of identification on packages.

There are several different materials to choose from when deciding on a packaging material for your product. Nowadays you can see most products are shipped in a cardboard box as it is lightweight and strong enough to withstand certain impacts. However, this all depends on the product being shipped. For example, if the company is trying to package a liquid, then they worldly contain it in cardboard. Instead, they would use a concealed plastic container or glass jar (Rundh, 2009). Additionally, companies need to look into the delicacy.

2.3 Current Packaging Methods

There are current packaging methods in place that differ from company to company. To ensure that all businesses use a fair set of packaging standards, the government released basic regulations to follow.

2.3.1 Government launched standards and regulations

The local and state governments have jurisdictions in regulating packaging, promoting government procurement of recycled products, and issuing guidelines for manufacturers. These jurisdictions are for the purpose of regulating waste (*Packaging,* n.d.). A major reason for launching federal packaging standards and regulations is to ensure manufacturers do not make false claims about environmental packaging. Despite the packaging sustainability guidelines, theories, strategies, and tools currently in place, there is still a lack of impact on the current system. Some of the reasons are listed below (Ma & Moultrie, 2018).

- The complexity of the problem creates obstacles for designers.
- Legislation or regulation limits the designer's scope
- Packaging types cause conflict with its sustainability aspect.
- The available methods and tools are not accessible.

In order to create an automated system to improve the packaging methods, the issues of the current system require more understanding and knowledge.

2.3.2 Issues

The issues with the current packaging methods are in production time, materials waste, and cost. Three large factors that packaging industries struggle with to improve sustainability.

1. Production Time

Production time is a large business component factored into how the packaging system operates. The manufacturing lead time is the time it takes for a manufacturer to make a particular package. For different types of packaging, there are varying production times for companies to consider (Ma & Moultrie, 2018).

2. Material Waste

When looking at issues with current packaging, it is important to consider the material that is being wasted. An article written about the proceedings of the 15th International Design Conference, explains that 65% of global solid waste is packaging materials (Ma & Moultrie, 2018). Packaging serves the purpose to protect and promote the product inside and once that purpose is served, it no longer has any more use, which leads to all the waste (Ma & Moultrie, 2018). Currently, waste reduction and recycling when it comes to packaging is being taken more seriously because researchers have found that the problem is deeper than being able to recycle plastic (Sonneveld et al., 2021). This has to do with the difficulty to recycle single-use plastics. The additives in the plastic material become pollutants when released into the environment (Carmen, 2021). However, most additives are bonded through a chemical reaction making it difficult to reverse and therefore, hard to recycle the plastic.

Invisible waste is another issue seen in current packaging which refers to the empty space in the package where the product is not making contact (Ehret, 2018). Figure 1 below shows an example of this empty space. Here is a very small package surrounded by a large box used to ship. This is a waste of material as the item is much smaller than the package but the extra cardboard is still used to package. It is an example of invisible waste.

Figure 1: Example of invisible waste

Without this invisible waste, packages become lighter and more suited to the product. Lighter packaging means there is less air pollution and less water wasted (Ehret, 2018). This is because the vehicle moving the package will not need as much gas due to the heavyweight, so many companies are opting for plastic bubble wrap packaging instead (Premack, n.d.). This combats the issue of invisible waste, but it does not solve the problem of recycling plastics.

3. Cost-Effectiveness

Cost is another large problem in the packaging industry especially in achieving a level of sustainability. In a study done, companies are less likely to use tools specifically created to improve the sustainability of the packaging design. The main reason that most users did not use sustainable packaging design tools is the perception that this would add extra cost and they believed that their consumers would not pay for it. The cost and the immature packaging technology make it difficult to follow sustainable packaging designs and development (Ma & Moultrie, 2018).

There have been studies on various packaging methods to find a material that is both cost-effective and sustainable. One study was done on conventional plastics. From a business perspective, plastic is an ideal material to use because it is cost-effective (Srinivasan & Lu, 2014). Some of the conventional plastics analyzed in the study were High-Density Polyethylene, Low-Density Polyethene, and bioplastics like bio-based HDPE. HDPE is a highly cost-effective material as it has wide-ranging design potential and processing flexibility. It is also stiff, strong, and resistant to chemicals and moisture. These properties make HDPE a common choice for sports drinks bottles, ketchup bottles, etc. LDPE bottles are squeezable and resistant to moisture. As such, they are used for bottling viscous liquids such as Honey and Mustard bottles in the FMCG industry. PP (PolyPropylene) is a material that is resistant to heat, chemicals, and grease. It is very versatile in terms of shapes and also acts as a good barrier to moisture. Bio-based HDPE is a successful invention in the field of bioplastics. Green HDPE has the same characteristics and properties as polyethylene made from fossil resources - it enjoys the same versatility in terms of applications. But the key difference is Green HDPE uses 70% less fossil fuel and has over 170% less greenhouse gas emissions per ton compared to petroleum-based plastics. Recycling 1 tonne of green plastic bottles can save up to 1.5 tonnes of CO_2. As such, bio-based HDPE is a viable replacement to conventional HDPE for FMCG packaging (Srinivasan & Lu, 2014).

2.4 What is currently being done to combat issues?

2.4.1 Machine Learning

There are many factors to consider when packaging a product. Characteristics like weight, geometry, necessary protection, and ease of transportation must all be taken into account. However, with the shipping industry expanding at its current rate and with all the different types of products that require packaging it is becoming increasingly complex to plan packages. Machine learning (ML) algorithms aim to optimize the performance criterion which evaluates the efficiency of fulfilling a given task by learning from (historical) data (Knoll et al., 2019).

A study done by students from the Technical University of Munich in 2019 formulated their own packaging planning process using ML in decision making. The system goes from understanding data (product characteristics: price, shape, weight, dimensions, etc) to data preparation, and finally modeling. Data preparation entails organizing existing literature into a schema for ML, and modeling refers to the synthesis of the ML system. In this study, the ML model was split into two: Packaging classification model, and the Fill rate regression model. The study managed to produce a model that was 84% accurate with its packaging solutions as compared to currently used methods (Knoll et al., 2019).

2.4.2 Automated Design

Automated design is a process that is increasingly finding its way into the packaging industry. The aim of an automated system is to increase efficiency in ordering and placing products in their shipping boxes. Some automated designs may include the process of assembling the empty shipping boxes and transporting them to various filling points.

A thesis investigated and designed an automated packaging machine capable of transitioning bulk vials into containers of 100 nested vials for Waters Corp (Ratner, 2019). One of the main reasons behind the need for this machine was to decrease the probability of damaging vials in transit. Human packagers are more susceptible to filling a box with 99 vials rather than 100. There is also the labor cost savings generated by increasing automation in the manufacturing process, as well as the ability to label their packages “100 vials” as opposed to “approximately 100 vials”.

2.4.3 Origami

Origami is used in the packaging industry in the form of cartons. It is the traditional Japanese art of folding a flat material into a 3D shape (Qiu et al., 2013). The idea behind designing a package using origami techniques is “less is more” (Llorens & Alarcón, 2020). A study was done at the Rochester Institute of Technology, Can Wang, MFA, looked at incorporating origami into packaging. Wang found that by using accordion-like origami folds, he could construct a reusable package for food and groceries resembling a bag. By utilizing this origami folding technique on opposite sides of the bag and the bottom of the bag, Wang argued that the contents were more protected (Wang, 2021). By using an origami technique to design packaging, a more protective construct is possible.

The origami style packaging is also beneficial since it can be pre folded and then constructed by a robot (Dai & Caldwell, 2010). The company then has an advantage of less manual labor allowing more energy for other aspects of the company. A research article written in the Journal *Trends in Food Science and Technology*, explains that a manufacturer would only expect about 2% rejects from a machine that constructs cartoons. Whereas they would expect between 10 and 35% rejects when constructed by manual labor (Dai & Caldwell, 2010). This further indicates that a machine package folder is more beneficial than a manually constructed one.

2.4.4 Sustainable Packaging

Sustainable packaging is another technique being researched to reduce the amount of waste produced from packaging. Since this concept is relatively new, it can be difficult to define it (Sonneveld et al., 2021). However, a definition will be created for the context of this project. The Sustainable Packaging Alliance (SPA) defines sustainable packaging in relation to four categories (Sonneveld et al., 2021) shown in figure 2.

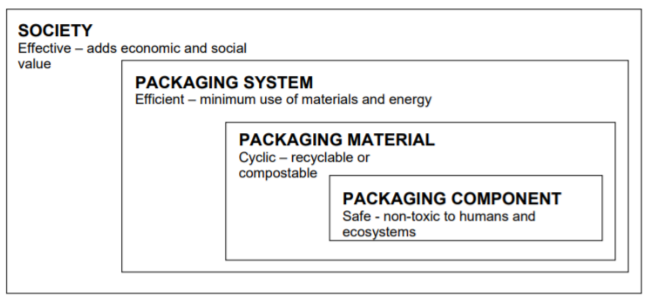


Figure 2: The four levels of sustainable packaging reproduced from by the SPA

In order for packaging to be considered sustainable it must address each of these categories listed in Figure 2(Sonneveld et al., 2021). Firstly, all packaging components of the material are non-toxic to both humans and the environment including eco-systems within the environment. All the material of the package must be sustainable in some way either biodegradable or recyclable, this includes the cushioning parts of the package (ie. packing peanuts). Next, the packaging system must be efficient which means the minimum amount of energy and materials is used. More specifically, constructing the package by an automated system for example means less energy through manual labor. For less material, this has to do with having the right size package and reducing invisible waste. Lastly, the package must have economic and social value to society.

3 Methodology

The development of packaging solutions for any given product needing to be transported safely is outlined in this chapter. The guidelines described for creating a packaging design follow the steps taken for product design. The purpose of this methodology is to establish the steps the team took to create an organized, sustainable, and reusable packaging solution that can be applied to any product needing packaging.

3.1 Addressing the Problem

The initial stages of design required the team to research the current packaging topics of concern to better understand how to address these common issues within our own packaging solution. Through our research, we determined that sustainability, cost, and production time are three major components complicating the current packaging system.

An aspect of the packaging method that is important for businesses to consider is the cost of packaging a product. A major reason for businesses to not use recyclable material to package their products is because it is an expense not worth considering. The deficit of cost-effective recyclable material has created an excessive amount of waste. In hand, the current packaging system lacks sustainability. Sustainability has become a prominent issue in the current system because of the waste produced due to current packaging methods and the cost-related issues. Plastic and paper are two major components used in packages for interior cushioning and protection from exterior factors. The lack of research and study done to improve the sustainability of the current packaging methods is resulting in large amounts of waste. Our team has researched different types of sustainable materials that can be used for packaging that focused more on the reusability of the package rather than recyclability. This will allow consumers to reuse the package holding the product for easy storage rather than disposing of the packaging after the product is successfully and safely transported.

3.2 Collecting Information

In the process of collecting information on the current methods of packaging, the team spent time researching, recording, and testing the current packaging methods. We observed and recorded packages delivered by the school's Mechanical Engineering department. Each package has recorded packaging types, amount of packaging materials, the empty space, weight, and package dimensions. The purpose of measuring and recording these packages is to better understand and address the wasted space and excess material there is in the current packaging methods. Appendix A shows many of the different items were measured and analyzed. In figure 3 below, multiple packages are shown with excess free space. Consolidation is available in Appendix A. The first item shown below is a box of shoes packaged in a much larger box: 25in x 40in x 14in being the larger box and then, 13.5in x 34in x 11in was the smaller inner box. Meaning there was 63.9% of free space. In the second image, the box has three items but space was also not optimized. This package has 69.2% of free space.

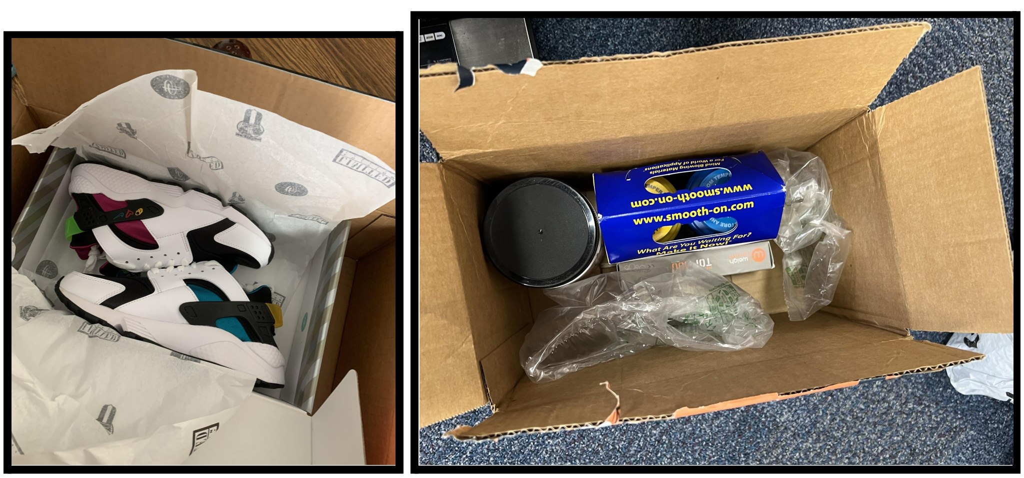


Figure 3: Examples of packages and items that were measured

Researching the current methods of packaging is a significant step to developing an improved packaging design solution. The team read through articles on developing packaging methods and current packaging studies, which are detailed in Chapter 2. The research is important in developing packaging design solutions because it gives insight into the current workings and issues faced. Taking the recorded data and research the team is able to generate multiple concept solutions that are cost-effective, time-efficient, and sustainable. With these generated solutions, we compared our packaging design solutions to the current packaging methods. By comparing the data from our developed solutions to the current methods, we can determine which concept solution is the best fit to meet our customers' needs.

3.3 Individual Packaging Solutions

Given various components, the team brainstormed packaging solutions for each component. The items were multiple parts of a prosthetic leg, a drill, a sharpener, and two large mass machines- a french fry maker and a medical device. Each item needing packaging was also given with a list of packaging needs that were asked of by the customer. To gather the customer's needs, there are multiple ways to obtain this information. However, for the specific task, it was critical for the team to prepare a list of questions asking for information that could be useful in the design process. From these questions, the team inputted the following information into a chart like the one shown in table 1.

Table 1: Types of Customer Needs For Packaging of Prosthetic Leg

Direct Needs	A packaging method that will protect parts of a prosthetic leg for future shipping.
Latent Needs	• A reusable packaging material that allows users to store parts. • Packaging that can be easily customizable

	for different parts.
Constant Needs	Able to have an interchangeable storage compartment in case one piece of the prosthetic does not need to be included.
Variable Needs	N/A
General Needs	• Protection of separate parts • Neat and organized • Available compartments to fit different sizes • Able to withstand changing weather conditions.
Niche Needs	N/A

3.4 Curated Method to Design Possible Packaging Solutions

To curate a packaging solution, the team followed the steps to product development. The steps included scoping the business and technical concerns, gathering customer needs, and establishing product functions. The business and technical concerns are important components to consider in the development of the product. Understanding the current packaging system gave the team more insight into issues of the system and areas for improvement.

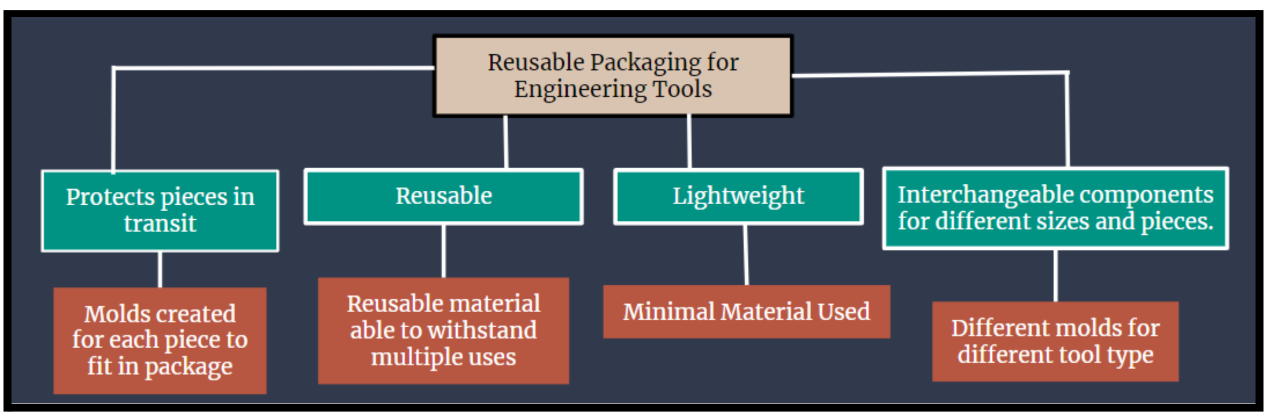


Figure 4: Mapping Customer Needs to Product Function for a Prosthetic Leg

Understanding the customer needs for a particular product was helpful in mapping the product functions. In figure 4, the team mapped out the customer needs for the prosthetic leg to the overall function structure. The function structure is the overall objective of the design. Without clearly stating in terms of the function, the structure cannot be properly designed. Identifying and evaluating these function structures is a vital piece of the design process. In the process of designing a packaging solution, the team evaluated the needs of the customer and created a chart ranking their value from a scale of 1-10 importance. From table 2, the user is able to see the requirement for each packaging and the importance of each requirement. Since our design must be reusable, that would rank as the most important aspect of our design.

Packaging of Engineering Tools: Rankings of Product Design's Needs

Need	Requirement	Value
Protect tools		9
Minimal Material	Lightweight	7
Used for students	Low cost	5
Reusable	High wear resistance	10
No movement during transit	Minimal displacement under velocity	8

Scale of 1-10 importance (10 being most important)

Table 2: Chart of Each Product Function Value Ranked

The method used to establish the functional structure was Functional Hierarchical Decomposition (FHD). Below, in figure 5 is the function decomposition of the packaging design for the engineering tools. Mapping of the product functions helped the team create a list of possible design concept solutions that meet the needs of the customer.

Functional Hierarchical Decomposition

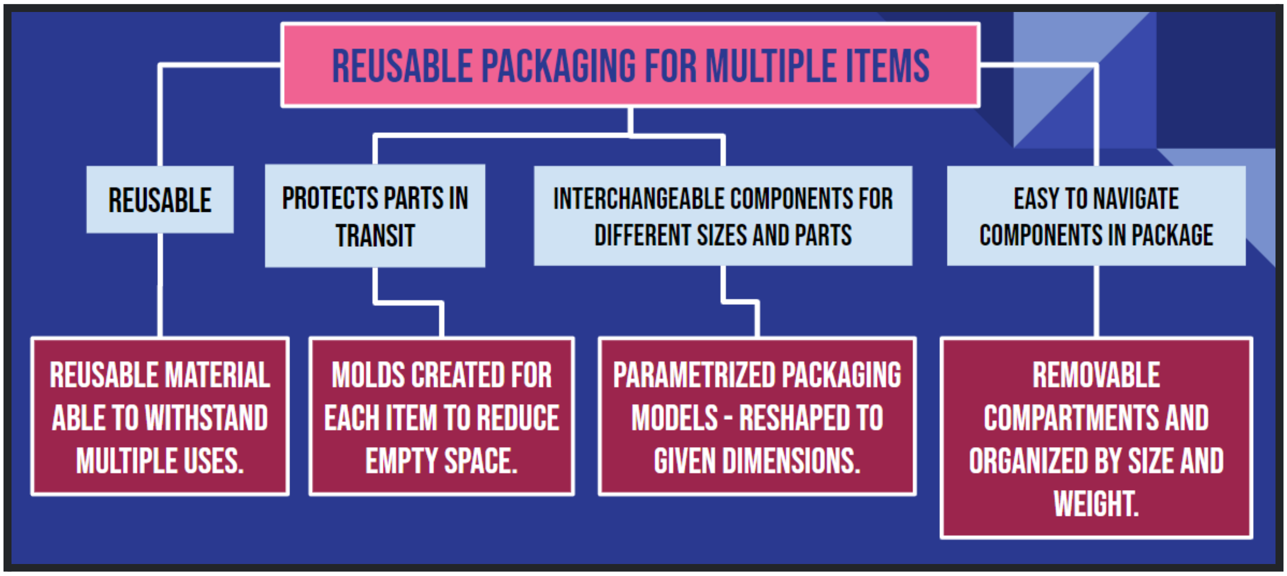


Figure 5: A map of the different customer needs to different product functions

For each need there is a different function the package must meet. The first need is reusability which is defined by the package being able to withstand many uses. This need is important as the entire package design is based on reusability. Secondly, the need to protect the parts while the package is being moved from place to place must be addressed. For this need, the package must reduce the space between the package and the item so that less movement will occur from within the package. Next, the package must have interchangeable components for multiple parts or packages that need to include some items but not others. This means the models must be able to resize based on dimension input. Lastly, the components of the package (if multiple) must be easy to interchange and place items into. This means the package must have removable components so that different items can be packaged within the same design.

3.5 Curated Flowcharts

Flow charts created were to map the needed information from the user about the item(s) needing packaging then the output would be a perfect package template. A template is a package design modeled in a 3D CAD program, that is able to be resized based on the item being packaged. It also will meet the following needs:

1. Protect the item in transit
2. Reusable
3. Lightweight
4. Allows individual items being packaged to be interchangeable.

Based on this, different flow charts were created for a user to follow based on the item's details. Below, in figure 6 the first iteration of the flowchart is shown.

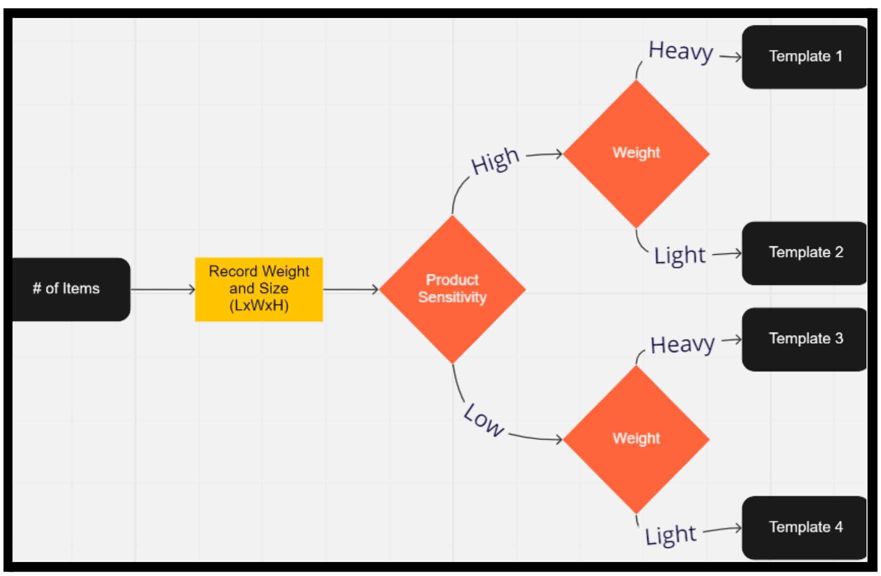


Figure 6: First Iteration of Packaging Flowchart

The design starts with inputting the dimensions, recording sensitivity, and then choosing between low and high weight. The template was then changed to include specific item sensitivity such as prone to breakage or temperature sensitivity. In addition, a template was added for item support (figure 7).

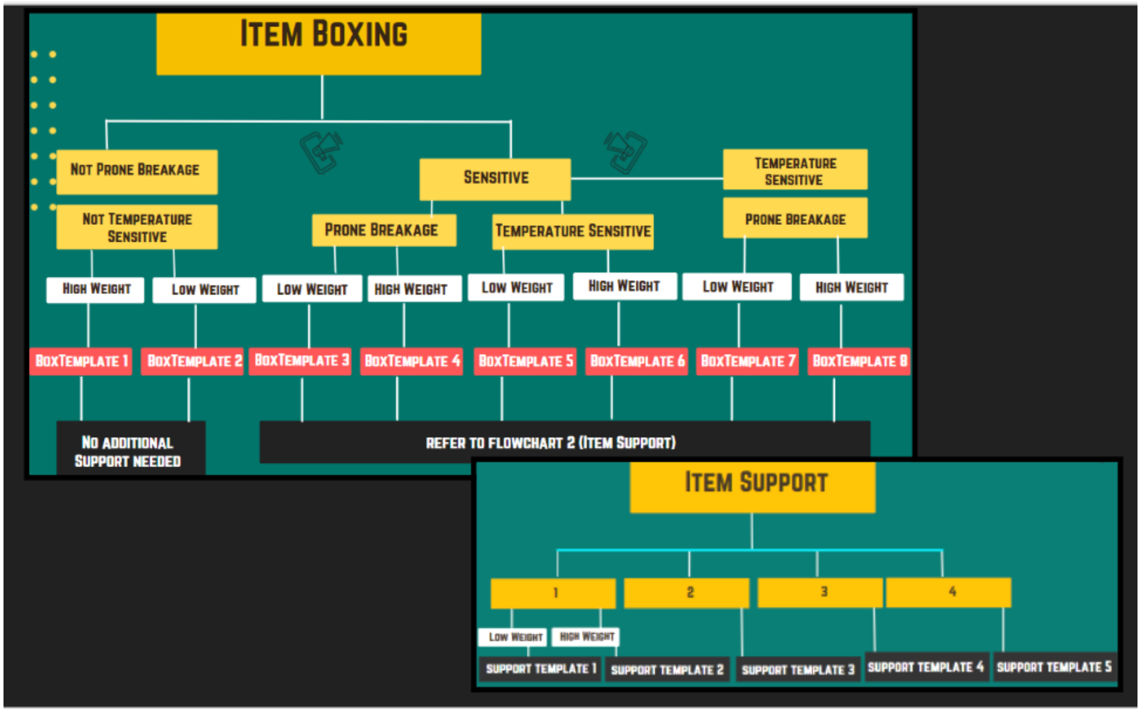


Figure 7: Second Iteration of Flowchart

Based on the selection, an item that is prone to breakage will have an additional support template. An item that is temperature-sensitive will have a template that has space for cold or hot packs to maintain the temperature of the item. The high-weight items will have a packaging template with handles.

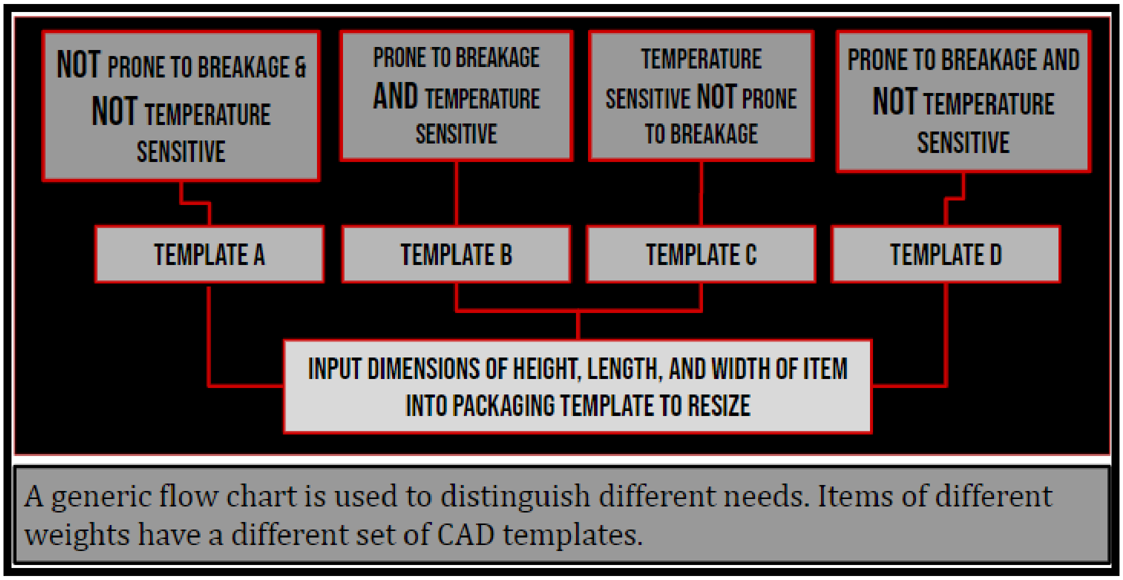
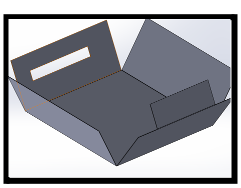
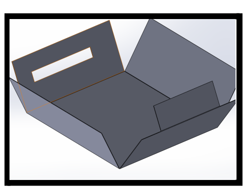
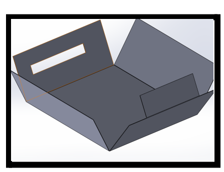
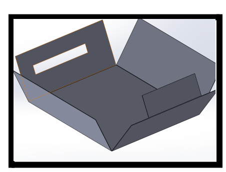
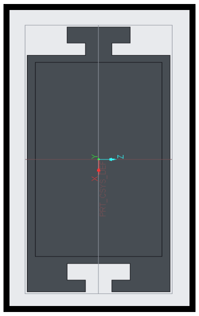
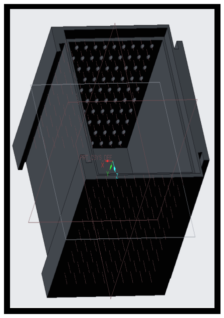
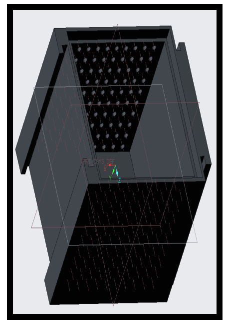
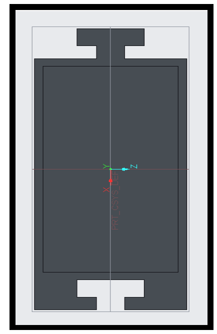
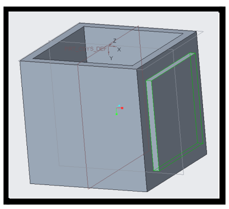
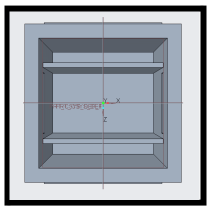
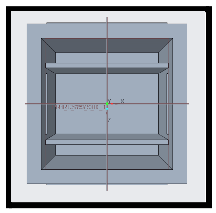
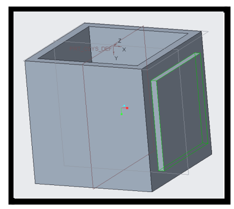


Figure 8: Third Iteration of Packaging Flowchart

The third iteration of the packaging flowchart was simplified so that the dimensions and weight of the package would be in the same section for user input; this allowed users to provide the same information for packages of different weight classes (figure 8). Table 3 below shows the different templates that would be produced based on the input of weight and dimensions.

Table 3: Templates A-D

Template A - Not prone to breakage nor temperature sensitive	**Template B -** Prone to breakage and temperature sensitive	**Template C -** Temperature sensitive and not prone to breakage	**Template D -** Prone to breakage and not temperature sensitive	
 • Regular fold	 • Extra space for cushioning between the fold and item • Extra space for insulating material	 • Extra space for insulating material to maintain temperature	 • Harder Exterior and space for extra cushioning material	**Thin item w/ Low Mass**

 • Tight fit of item package	 • Thicker walls • Holes in walls to allow for airflow	 • Space between item and exterior for insulating material	 • Thicker exterior to prevent breakage	**Medium Mass** -allows for multiple item packaging ***These templates have latch design to allow for attachable packaging items.***
 • Tight fit of item package	 • Thicker walls • Slots in walls to allow for insulation	 • Slots in walls to allow for insulation	 • Thicker exterior to prevent breakage	**Large Mass -** Larger items have a generic design without the latch addition because of the weight differentiation.

3.6 CAD Templates

In the process of developing a flowchart, the team had created four computer-aided packaging design (CAD) models that met each requirement shown in figure 7's flowchart. Packaging templates were created using Solidworks and Creo, going through many design iterations. The first way to start was with a 'normal' item meaning an object that is not breakable, not temperature sensitive, and under 10lbs (mass). An example of this could be a water bottle, or a measuring tape. This way the template did not have to have a thermal layer, impact insulation, or handles. The first template could be simple and refined from that point. This means that a more complex item (such as one that needs additional support) could be packaged in the simple package, as the extra features could be designed and suppressed or unsuppressed in the CAD model. For example, the handle feature shown in figure 12 could be added for a heavy item and removed for a lower-weight item. This is the same with the thermal barrier as seen in figure 12 as well.

The goal was for each template to be able to attach together. The purpose of this latching mechanism was for multiple items to be transported together, even if they are not suited for the exact same packaging. For example, there may be a larger nonsensitive item and a sensitive item that needs to be packaged together. The smaller sensitive item will have support so it will end up needing the same dimensions for a package as the larger item. This way multiple items in the same shipment could go in different boxes if they were unable to be packaged together, the design concept shown in figure 9 was the very first template created for the flow chart. We also came up with the idea of connecting two packages together. However, this design would not work if the items were too heavy as the latching mechanics did not allow for such. To address this, we came up with multiple different latching mechanisms, of a recess and corresponding progression.

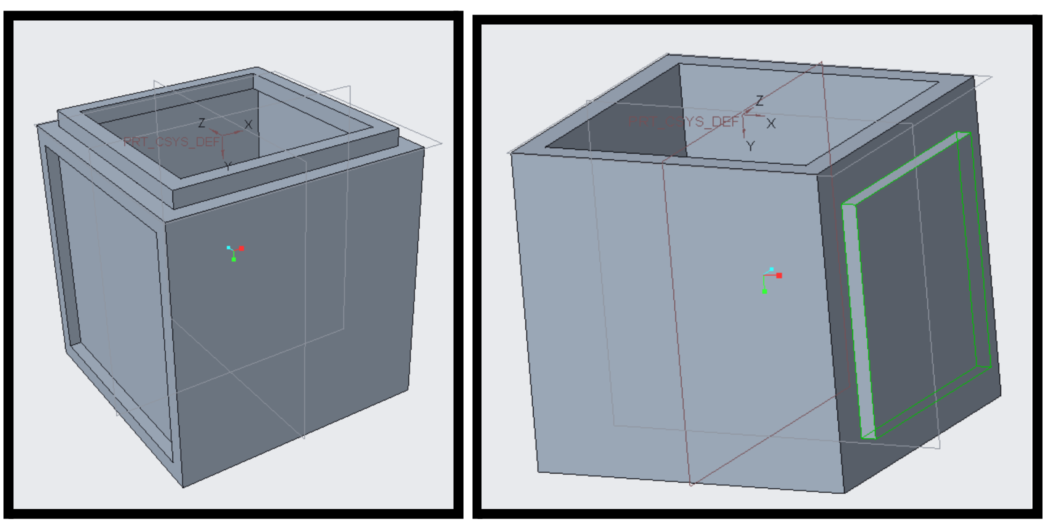


Figure 9: First Attempted Template Design (left image shows indent for the right image to fix into)

The next template evolution resembled a lego brick having notches on one side and corresponding holes on the other so two boxes could snap together which is displayed in figure 10. A big issue with this design was parametrizing the notches and holes. When the box had to be scaled up, there was debate about how to parametrize the notches and holes. If the box had to be twice as large as the original template should there be more notches added to the array or should the size of the notches and holes be enlarged? This means if a box was 6 in x 6 in x 18 in, there would be an array of 9 holes/notches. But if the box needed to be 12 in x 12 in x 36 in, there would now be 36 holes/notches which would not fit together. The team could not find a correct answer when testing the box through the flow chart so the design was changed in order to fit more possibilities. It is also worthy to mention that the tolerances for this idea were complicated when creating the legos with a 3D printer.

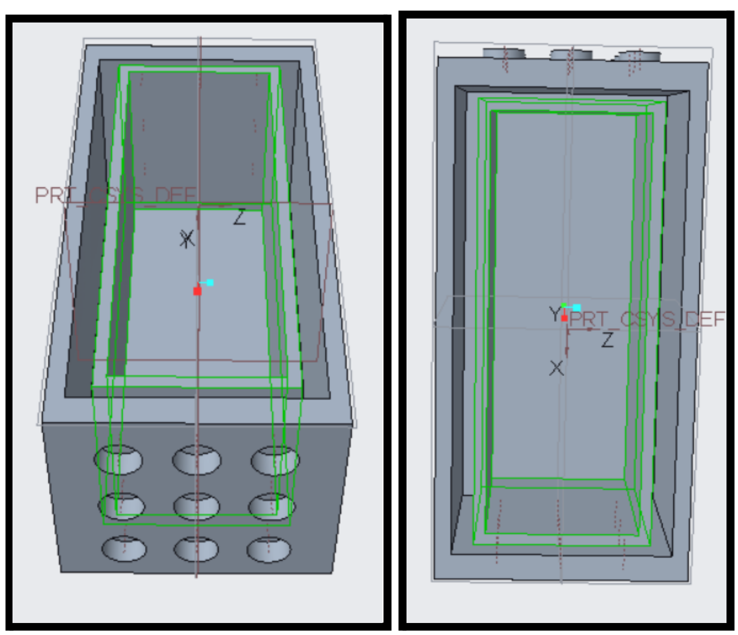


Figure 10: Second template design

The next simple model was created after a pause in design to test different latching mechanisms. This box featured two long rectangular rods on one side and two corresponding slots for them on the other as shown in figure 11. The dimensions change with the changes in the inputs. See chapter 4.1 for resizing images. This design allowed the boxes to attach together and worked well when 3D printed.

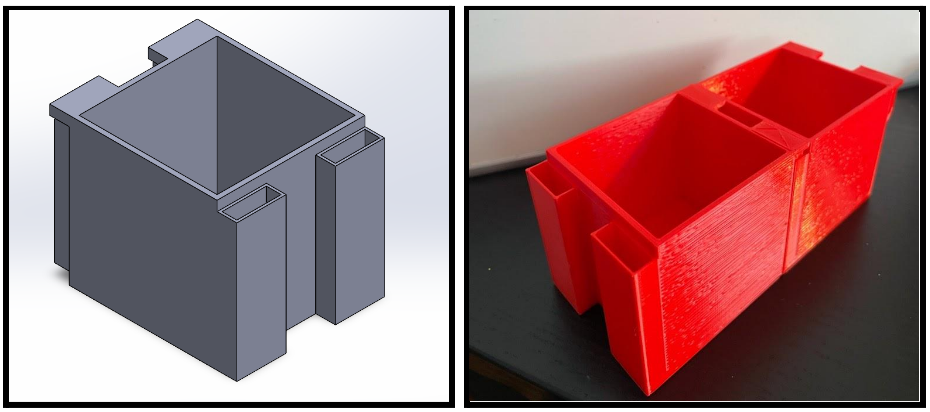


Figure 11: Latching Mechanism

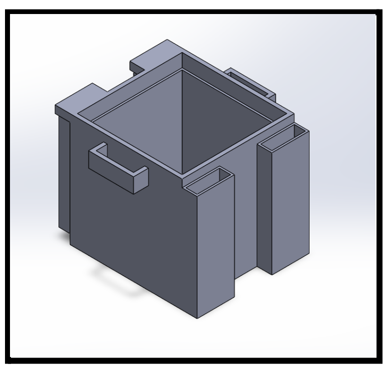


Figure 12: Thermal Template

The model worked well with an addition of thermal layers for items that were temperature sensitive shown in figure 12. This template has an inner layer where heating or cooling material could be placed in order to maintain the specified temperature of an item. As the template is resized the inner layer will change as well. However, the issue with this design came when attempting to parametrize it for an object that is long and flat like an iPad or a 3D printer bed. This model was not able to shrink down as nicely so another template was developed for items that were long and flat. This model shown in figure 13 used an origami-style to package items of this shape.

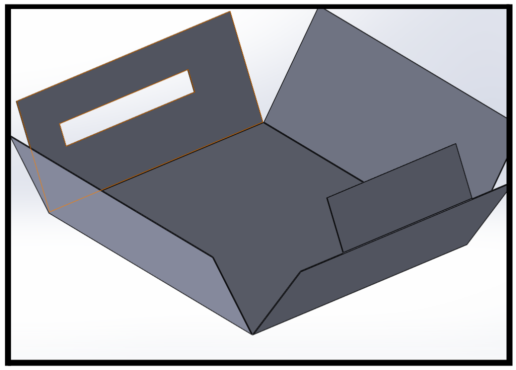


Figure 13: Template for Flat Items

4 Testing

In this section, the team examined the packaging design and conducted different studies to provide information on the current model. From these studies, the team was able to evolve design solutions. The analysis process consists of testing models' reparameterization and performing simulations of different packaging scenarios.

4.1 Testing Reparameterization

To test each model's parameterization, the team opened the computer-aided packaging design in Creo and adjusted the set variables: pl (product length in inches), pw (product width in inches), and ph (product height in inches).

If the Computer-Aided Design resized with the change in length, width, height, and without displaying errors from reparametrization, then the design was ready for the next step of the analysis. Figure 14 below shows an example of the temperature sensitive template being resized for two different dimension inputs.

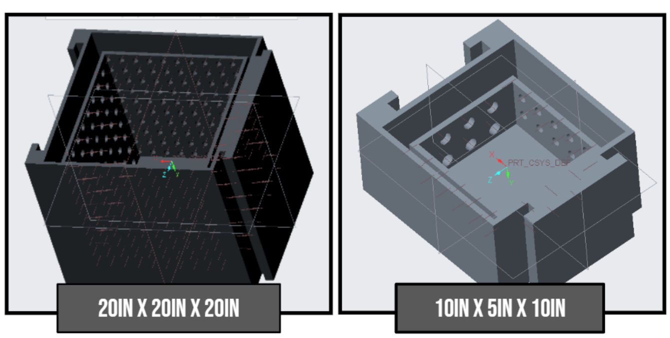


Figure 14: Example of two different parameterizations on one template

The parameterization equations are shown below in figure 15 for Solidworks and in figure 16 for Creo PTC.

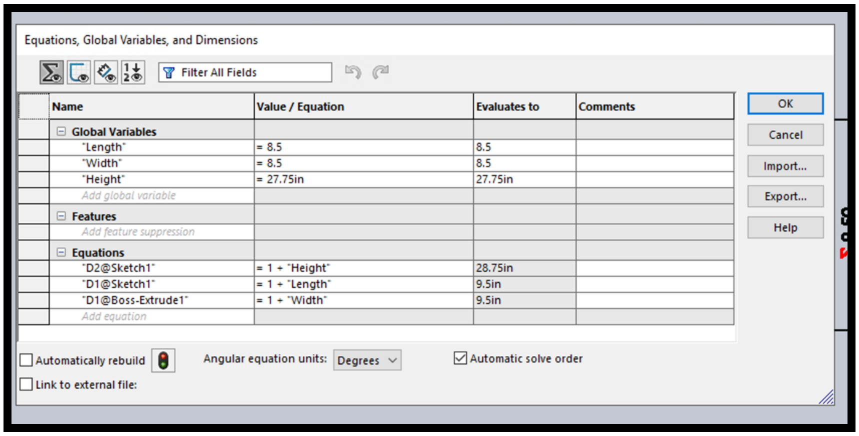


Figure 15: Parameterization equation used in Solidworks model

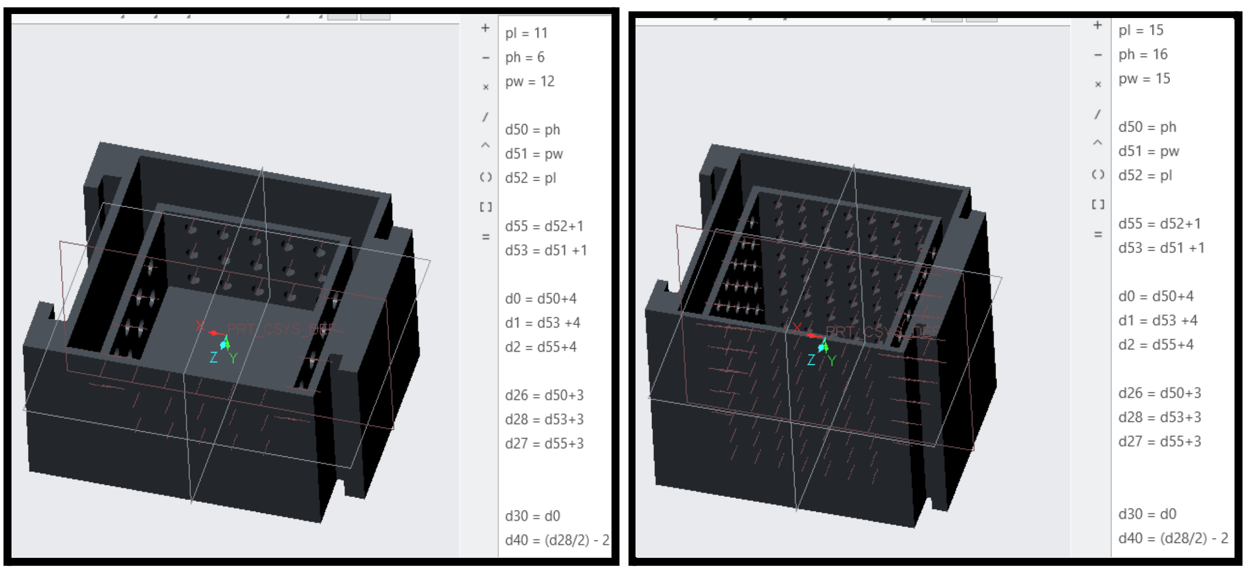


Figure 16: Reparametrization of Design Template in Creo

The parametrization of figure 16 was done in the relations window of Creo, where we were able to take the program's labeled dimensions and write equations to relate one to the other. These established relationships allowed for the designed templates to flex to new given dimensions. In figure 16, the variables pl, pw, and ph are defined to the model's length, width, and height. By altering the defined variables, the model successfully flexes with the given dimensions.

4.2 Evaluation: In ANSYS

The next step in analyzing the developed solutions is to evaluate the design in different scenarios. Prior to importing CAD files into ANSYS and performing live simulations, the team recorded scenarios of potential forces acting on the package. Figure 16, seen below, shows the packaging scenarios considered.

Forces Acting on Packaging Scenarios

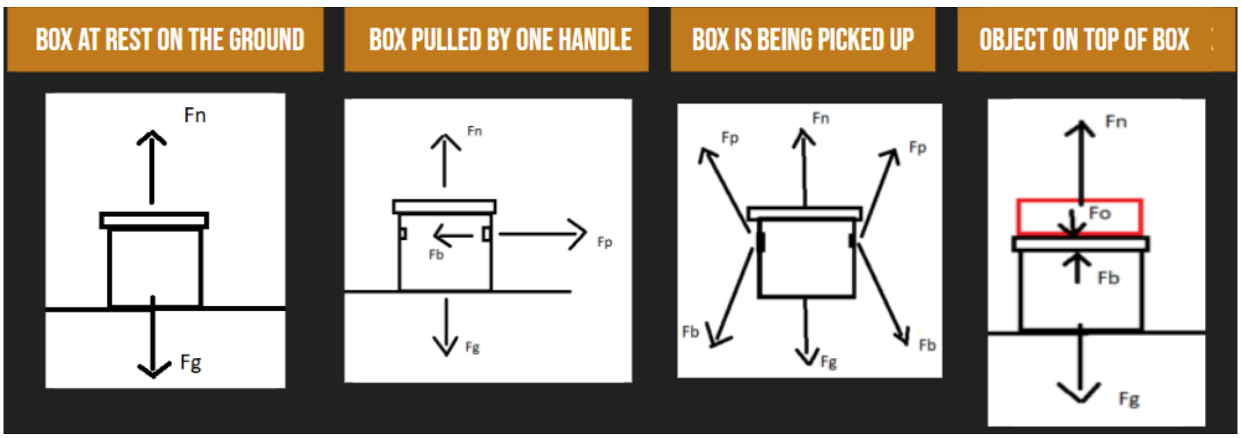


Figure 17: Forces Acting on Packaging Scenarios

Once we recreated each scenario in ANSYS, the team made a list of materials to test. The list of materials selected for testing was PLA, PS, ABS, and PE. The program, ANSYS was chosen for evaluating deformations within the models. Our first design concept solution was opened in ANSYS and analyzed. The figure below shows the model's deformations when a force is applied before and after. A force of 10 Newtons was inputted into this design. This is shown in figures 18 and 19 below. From the resulting simulation, we can see a lot of deformations in the model. The team looked into designing a new handle mechanism to ensure better distribution of weight and support.

Static Structural of Model Force Direction

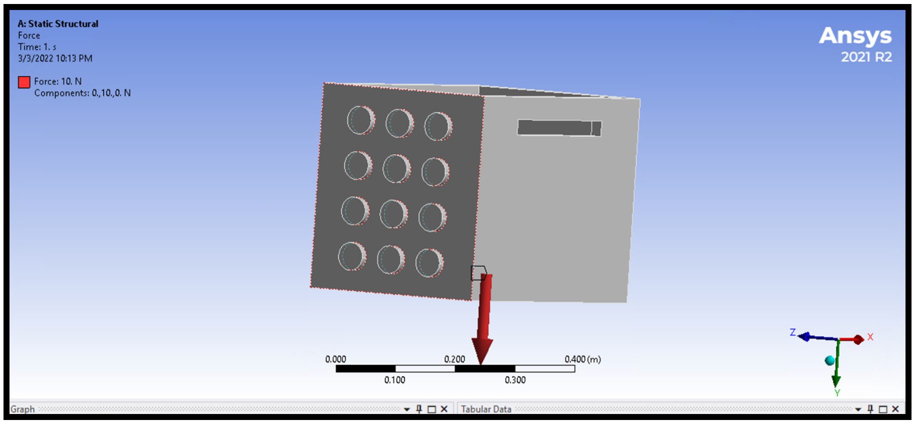


Figure 18: Force applied downward on model as weight load

Static Structural of Model with Applied Force

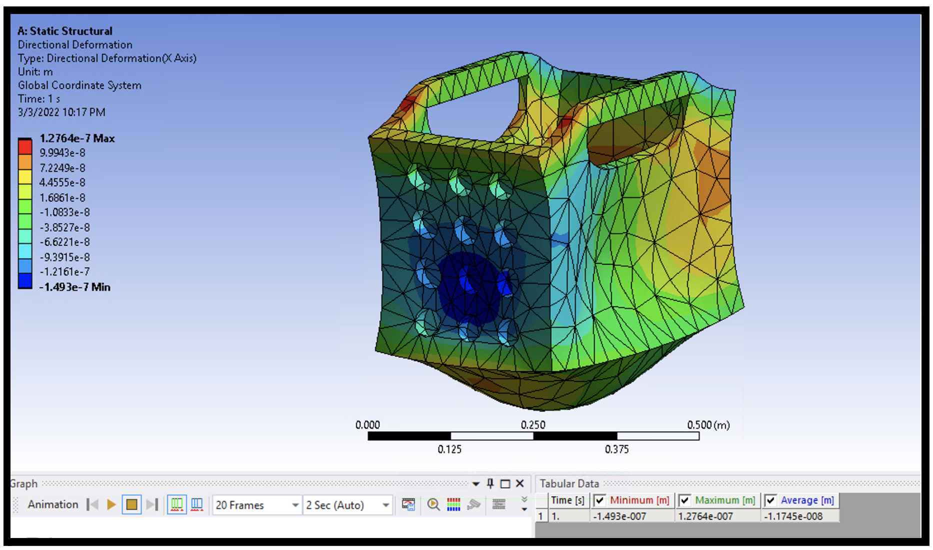


Figure 19: Model with downward force applied

From this result, we can see a lot of deformations in the model. The team looked into designing a new handle mechanism to ensure better distribution of weight and support.

4.3 Parametrization/Flowcharts

The finalized flowchart and templates successfully packaged the items we tested. The flowchart was tested by choosing an item and following the chart. The templates were tested by choosing different items and inputting the dimensions to see how the template would resize. The first tested item was a battery. After following the flowchart the resulting package was a heavy, non-sensitive item template. The template without being resized is shown below in figure 20.

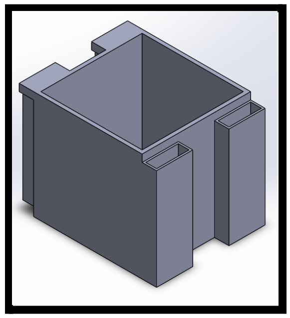


Figure 20: Resized battery template

Next, the dimensions of the part were taken. The dimensions are 7.5in x 6.83in x 7.09in. We did this step using a measuring tool in CAD software. The measurements for pl, pw, and ph are shown in figure 21.

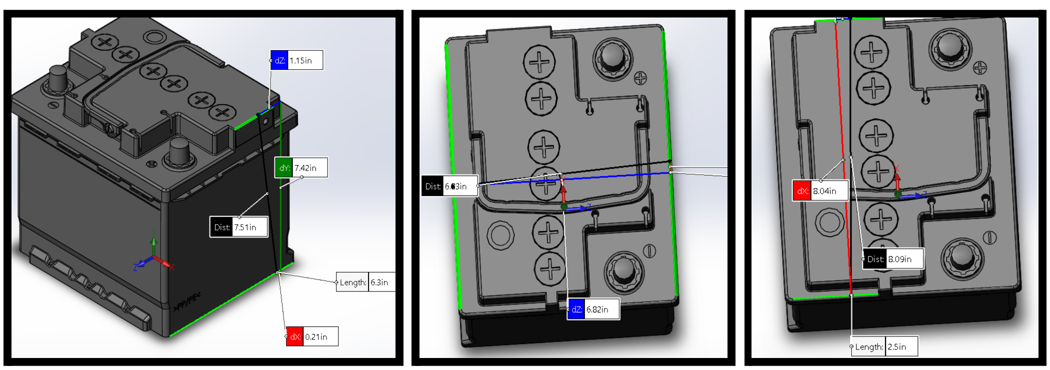


Figure 21: Battery Dimensions (7.5in x 6.83in x 7.09in)

Lastly, the dimensions were inputted into the software and the battery was assembled with the resized template. See figure 22 below.

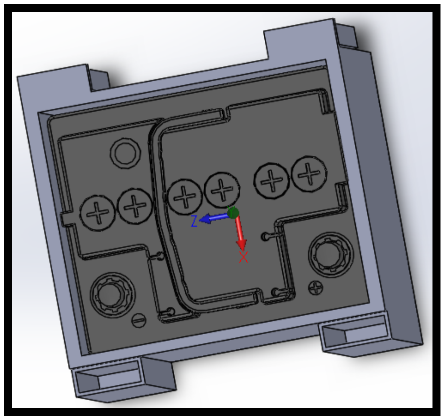


Figure 22: Battery and template assembly

Another example is shown below for a thin, sensitive item, an Ipad. Figure 22 shows this.

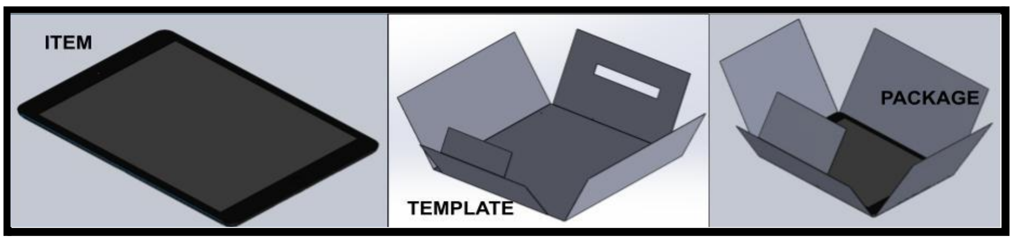


Figure 23: Thin item package

This shows that our templates were resized correctly based on the item's dimensions. The final process resulted in a more sustainable packaging system for two reasons. The first is the fact that our design reduced the amount of free space in packages measured from 57% to 10%. The percent of free space was calculated by taking the maximum pl, pw, and ph finding the volume, and then subtracting it from the volume of the package. This number is then divided by the package volume and multiplied by 100 to get the percent. Based on the reduction of free space, this means fewer materials will be used when creating the package. This will save the consumer money due to less money spent on materials. This also makes the package sustainable because of the reduction of materials being used. Less large packages with small items will be produced meaning less wasted space and therefore, sustainability. The second reason is the fact that the system is designed to be reusable. For example, in an industry often packages are sent back and forth with the same item. When replacing an electric vehicle car battery the company often takes the old battery to recycle due to the valuable materials still in the battery. In this case, the new battery would come in a package using our design and the old car battery would be sent back in the same package. This way the company only purchases one package for multiple items. Because of the reusable aspect, the package is sustainable since less materials will be put into the environment.

4.4 Finalized Templates

We successfully created 4 templates, with 12 possible iterations that correspond to our various flowchart outputs. Variations in the templates span from internal support structures needed for temperature sensitive products to foldable designs for thin products. Our final iteration for templates implemented improvements in our latching mechanism. After printing a 40 percent scale model of the box template, we realized a design flaw in our concept. The connection point between the two models was not structurally sound enough to sustain any substantial load. After analyzing the physical model we revived the model to be connected along with the entire height of the template. This would rid our design of its structural weakness

5 Conclusion

Starting the project, we took the challenge of creating a customized packaging solution that is reusable, sustainable, and protects the item during transit. We faced the issues of what types of characteristics of the part we needed to consider, such as size, weight, and vulnerability of the product (ie. temperature sensitive, prone to breakage). We needed to create a design that would output the perfect package for and input product specifications.

5.1 Broader Impacts

5.1.1 Societal and Global Impact

The impact our project has on society and globally is large. We are proposing packaging solutions that have not been tested or used in the real world before. This is due to the reusable aspect instead of throwing away or recycling the package. As a society, the mindset of throwing away packaging will have to be changed. However, if this is possible, it could change the way trash and packaging is thought about globally. This change of reusing could also affect other aspects such as food and cosmetic containers. Society may drift towards a more reusable approach to all types of packaging after they know it is possible and works.

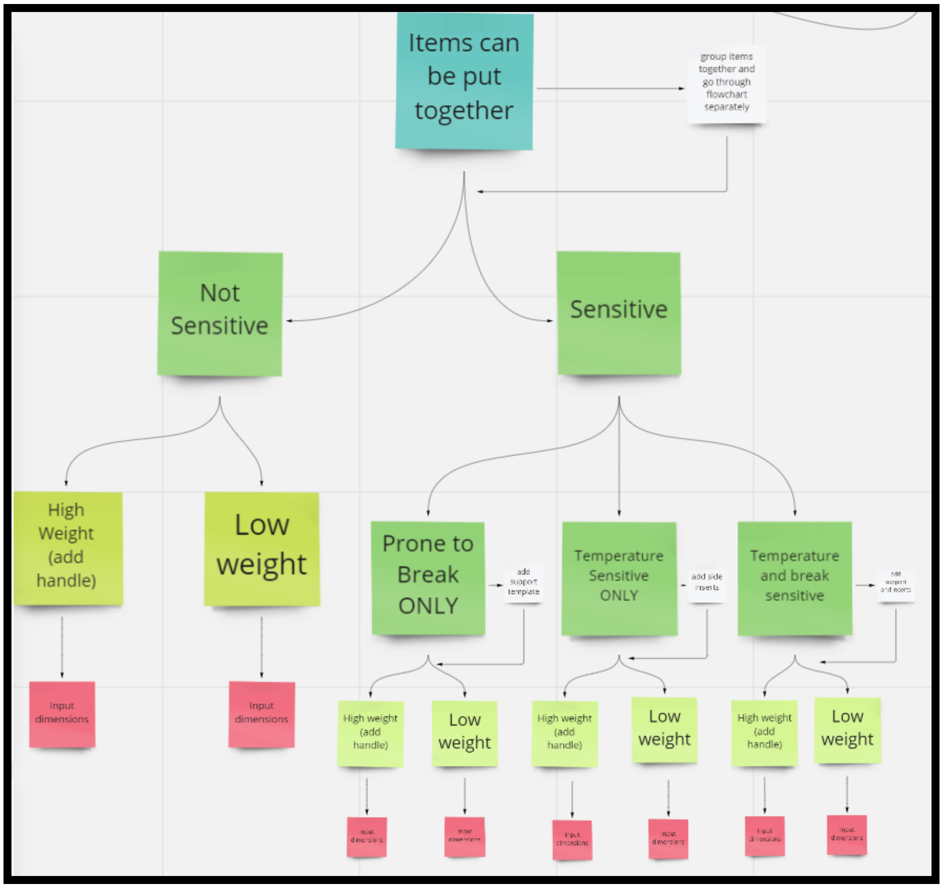
5.1.2 Environmental Impact

The environmental impact is also large. Shifting to reusing packaging, means less packaging waste will be put into the environment. As mentioned before, 65% of solid waste is from packaging. If this number is able to be reduced, there will be less waste going into landfills and the ocean. This results in long-term sustainability as the waste is reduced over time while the shift from disposable packaging to reusable packaging occurs.

5.2 Recommendations

5.2.1 Multiple Item Package

When trying to package any item into our system, we noticed that packages with multiple items were difficult to put through our flowchart. The issue lies in the fact that there are many inputs with multiple items and it is challenging to find a perfect package with such different inputs. The solution we came up with is using similar-sized items to be put into the same package. We also designed a flowchart that would be used so one item would be put through at a time and the question of more items needing packaging would be asked. An example of the flowchart is shown in figure 24 below.


Items can be put together
group items together and go through flowchart separately
Not Sensitive
Sensitive
High Weight (add handle)
Low weight
Prone to Break ONLY
add support template
Temperature Sensitive ONLY
add side inserts
Temperature and break sensitive
Input dimensions
Input dimensions
High weight (add handle)
Low weight
High weight (add handle)
Low weight
High weight (add handle)
Low weight

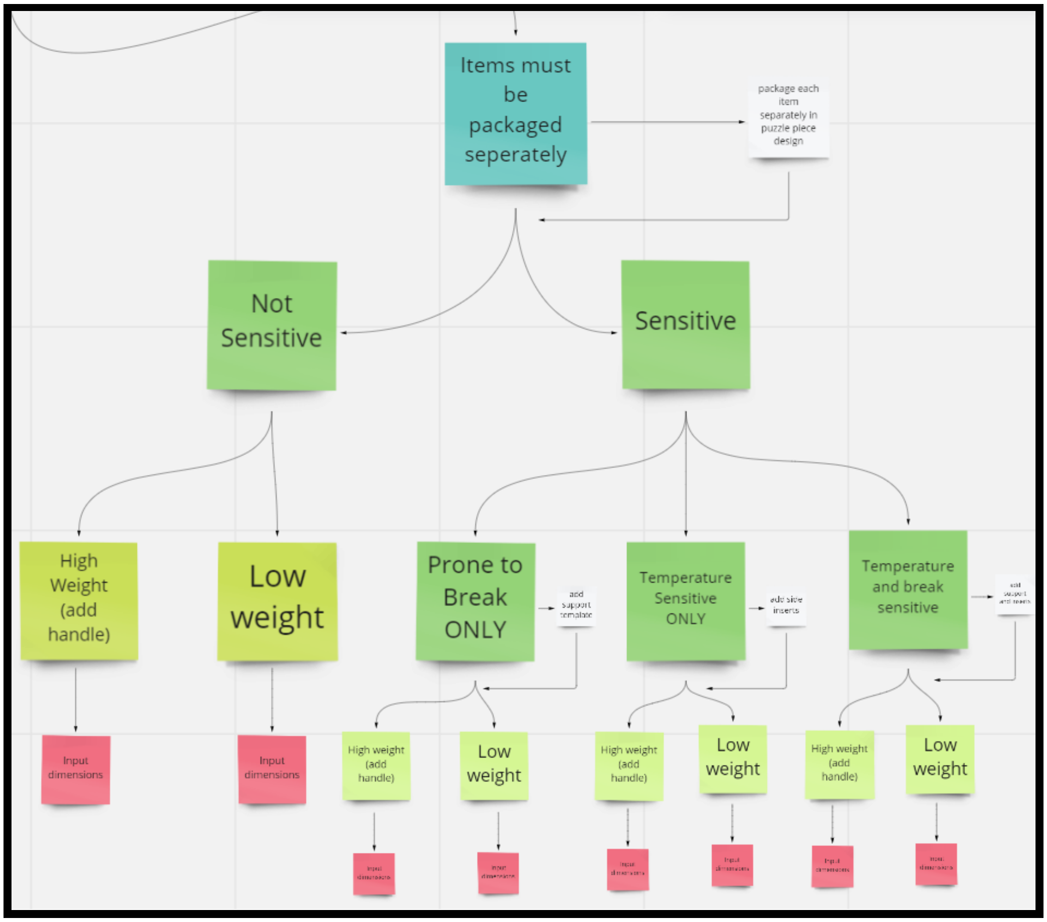


Figure 24: Multiple Item flowchart

The way this works is that the user must answer whether the items can be put together or not. In the case that items can be put together, the user will group the items as one and go through the rest of the flowchart answering the questions as if they were 1 item, resulting in a singular package. In the case that the items can not be put together, the user will go through the flowchart multiple times with each individual item resulting in multiple packages.

A suggestion for adding multiple items to one package is by using layers. The Solidworks template below shows two layers with slots for specific items. This design is shown below in figure 24.

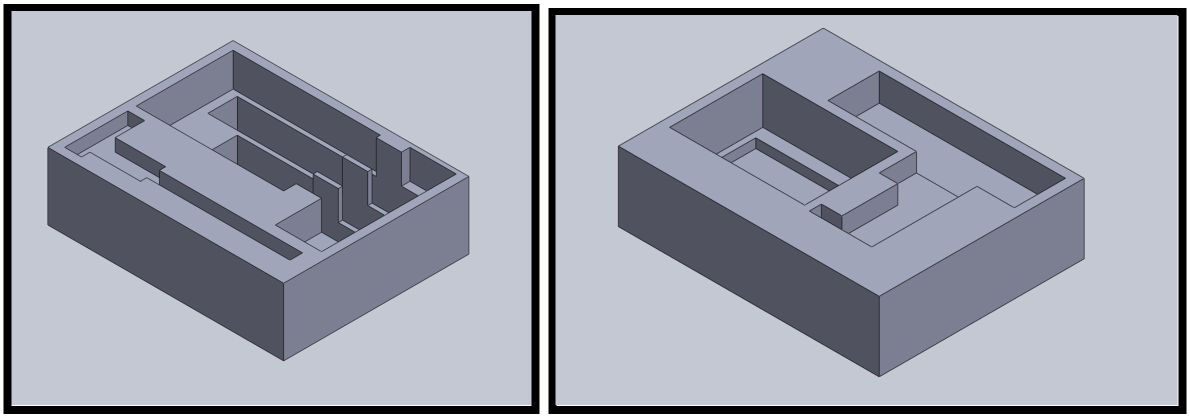


Figure 25: Multiple item templates, left figure is for multiple screwdrivers, safety glasses, and a digital caliper, the right figure for an electric pencil sharpener, battery, and electric screwdriver

This design also saves space by having the single layers have slots within the slots so a heavier item would be placed under a lighter item. For example, in the right image, there is a deeper cut for a heavy drill battery and the larger cut is for an electric pencil sharpener that can safely go on top. This design would potentially work for other items similar to these.

5.2.2 Materials Recommendations

One facet of this project that would benefit from further thought would be the materials the final packaging would be produced with. When analyzing our models we realized there was a greater emphasis on our material choice based on our goal of reusability. This emphasis was amplified when considering fragile and/or temperature-sensitive products that required additional support structures internally. Our efforts were more focused on proof of concept, explaining our choice to 3D print our models. However, this is not a viable production method on a scale as large as the packaging industry.

Another materials aspect would be looking at what material is best for a specific item. For example, an item that needs to maintain a certain temperature may benefit from being packed with a material that has low thermal conductivity. This means that the package will be even better suited for the item making it even more customizable. However, once again it is important to consider production on a larger scale and this solution may not be as ideal.

5.2.3 Package Lids

Our models do not incorporate any designs for how to open and close the packages. Our brainstorming sessions resulted in ideas akin to a sliding top and a latch mechanism. Another promising avenue was using snap-fit lids. Out of the three options, this seemed to be the one with the least complexity in designing. Its challenge is more focused on tolerancing in production. The lid is important to the reusability aspect we are trying to accomplish. By adding a lid, consumers and industry will be able to repurpose the package multiple times. It also allows for less use of tape and other adhesives that tend to be used to hold packages together. An image of the attempted snap-fit lid is shown in figure 26 below.

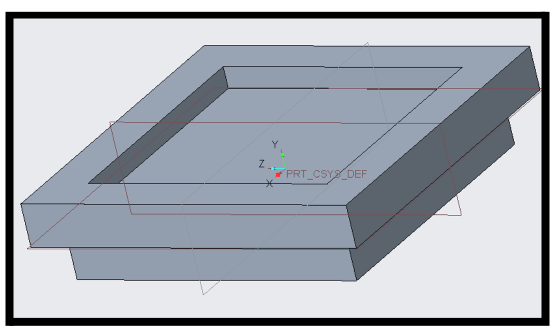
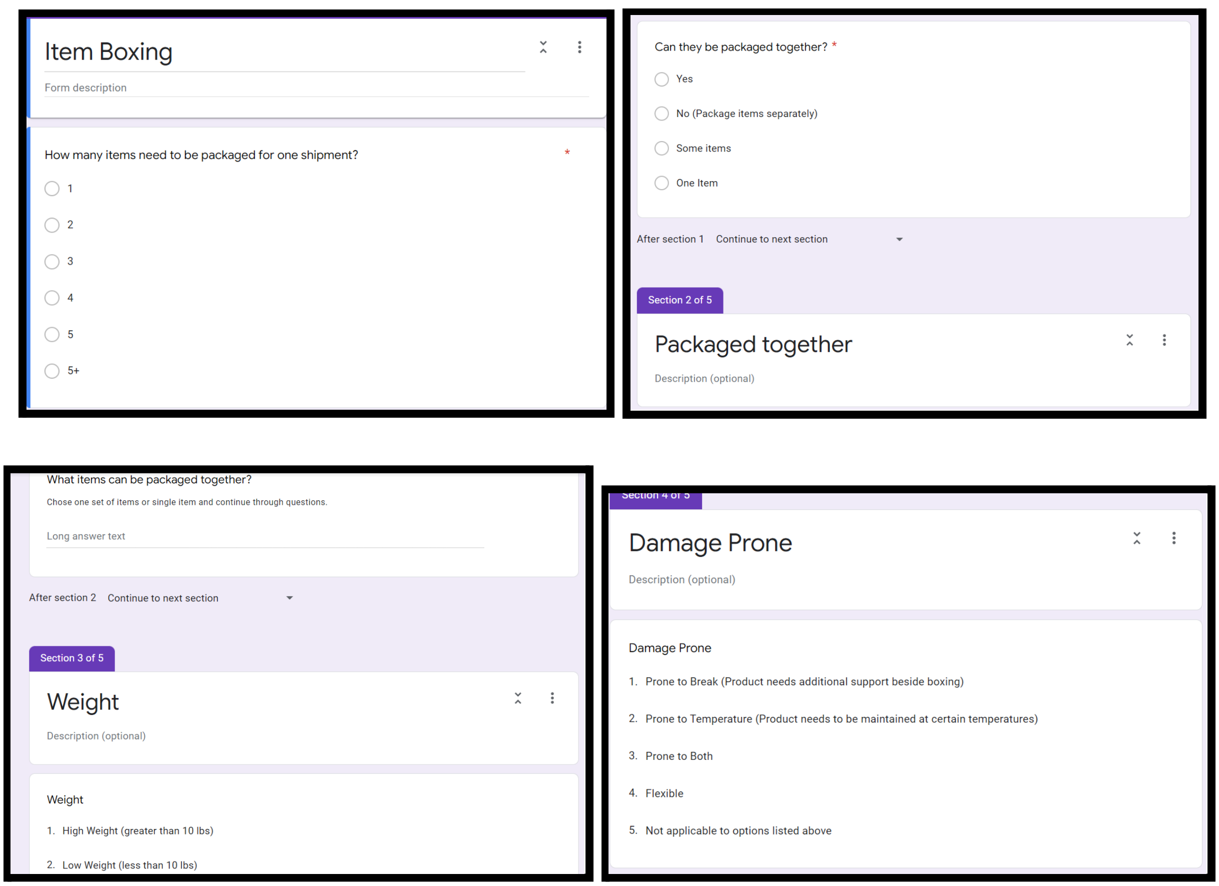


Figure 26: Example of Lid

5.2.4 Automating Flowchart

In efforts to fully automate our project, we began by creating a google form for consumers. The idea was that users would be able to input all the information about their intended product to be shipped (dimensions, weight, durability, material, etc) and with that information, we would be able to determine the proper template. Furthermore, we coded the response sheet to display which template should be used based on the questions and was successful. Below in Figure 27, the questionnaire is shown.



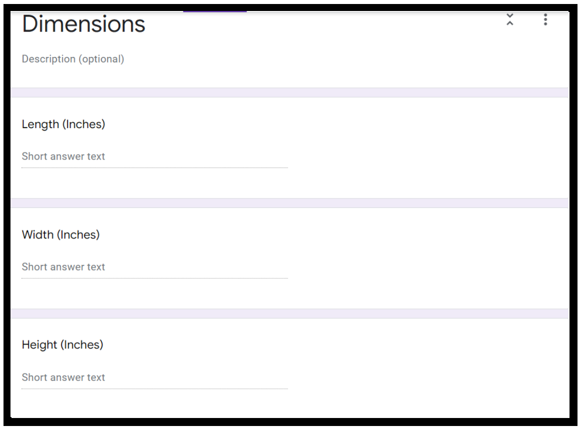


Figure 27: Example of packaging questionnaire for user input

Looking at the questionnaire the first question is how many items are being packaged, if the answer is more than 1 it will proceed to the question asking if multiple items can be packaged together, which will then lead to the question of what items are able to be packaged together. Next the user will be prompted to go through the rest of the questions (damage prone, dimensions, and weight) multiple times using either one item or a group of similar items which are being considered one item. If the answer to the first question was one item, the then user will be led through the damage prone question and lastly to weight and dimension question.

As for the future, we recommend creating a program that will take to users inputs and output the suggested templates with the adjusted parameters of the packaging to correctly fit the product. Professor Radhakrishnan and our team plan to endure this challenge over the Summer.

5.2.5 Ansys Simulation

We made some attempts to acquire data on load limitations and deformation while working on this project. However, due to time constraints, we decided to place our focus on refining our flowchart and template designs. This project would benefit greatly from the structural analysis of the templates. As mentioned in the data analysis section earlier, our exploration of ANSYS software showed promising signs and avenues in regards to determining which material would be best to manufacture out of a large scale.

5.2 Project Experience

During the project, we were able to apply our previous knowledge of research. During our previous year, we all completed extensive research papers on a given topic. We also had to complete specific deliverables for these projects. In this sense, we were able to start our research confidently. From previous classes, we understood mechanical design and the steps that needed to be taken. Overall, we were prepared to research and design a product.

However, we did not know everything. From this project, we were able to learn about communication between five busy group members and what it took to work together. We often had to meet in separate smaller groups and then report to the whole team about what it was that had been done. We also learned the extensive design behind the packaging. Before starting our project, it seemed that packaging an item would be simple, and the complex aspect would be the material of the package. We soon learned that the design behind packaging was more complex. Because we wanted to make a customizable design for each item that needed to be packaged, we had to consider almost every aspect of the item. This means looking at specific dimensions, and how much protection each item needs. Is it sensitive to temperature? Will it break when it drops? How heavy is the item, does the package need handles to support the weight? These are just some of the questions we had to ask ourselves. Lastly, we learned the challenges of starting a new project, with minimal sources to reference. As a customizable, automated packaging solution had never been created we spent numerous hours working on parametrizing the CAD models in order for them to reshape based on dimensional input.

Finally, there are a couple of aspects of our project we wish we knew before starting. The first would be how much time the design aspect would take. We initially planned to automate our system but due to the lengthy process of designing it, we did not have time. The second thing that we wish we knew was more in-depth CAD design. A lot of time was spent figuring out how to actually parametrize the models in Solidworks and Creo, if we had known how to do this prior to the project, more of a materials focus could have been taken.

6 References

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7 Appendix

A Items Measured

Figure 27: Space heater

Figure 28: Screws/Bolts

Figure 29: Plastic pins

Figure 30: Laboratory Film

Figure 31: Lenovo Monitor

Figure 32: Ceramic Tubes

Figure 33: Converse shoes

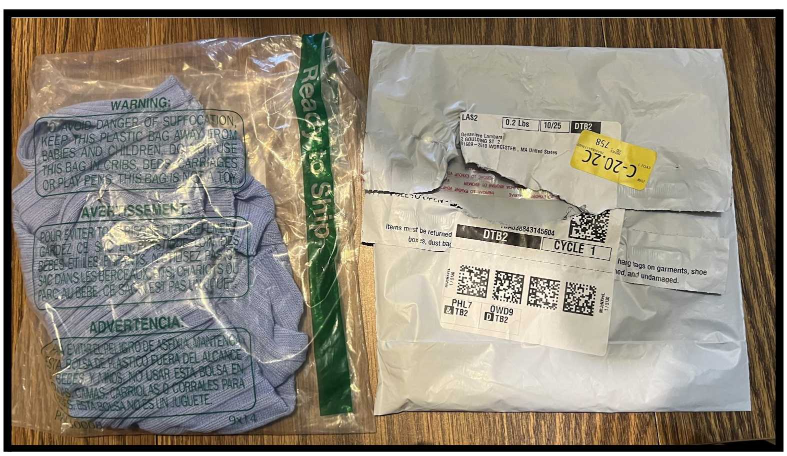

Figure 34: Clothing, tank top

Figure 35: Multiple items in package

Figure 36: Contact lenses

Figure 37: 3D printer filament

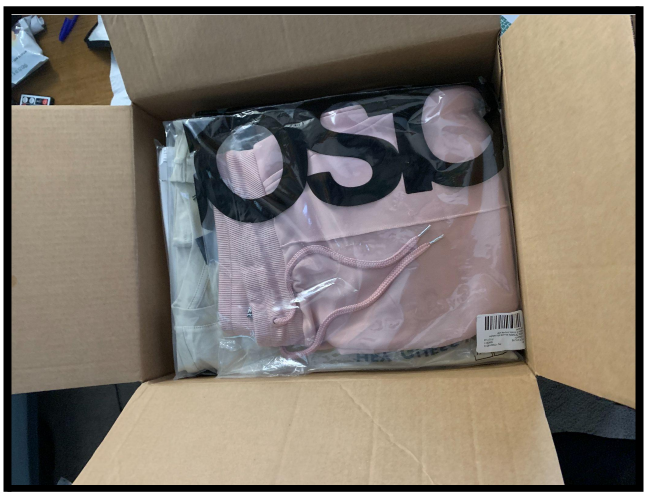

Figure 38: Clothes

Figure 39: Machine parts

Package Data

B Link to CAD template

[templates]

[mqpPackaging.zip]

Automated Packaging Design Method for Reusability

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