

CASE STUDY IN RAPID PRODUCT DESIGN AND DEVELOPMENT

by

Garrett L. Winther

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the Degree of

Bachelor of Science

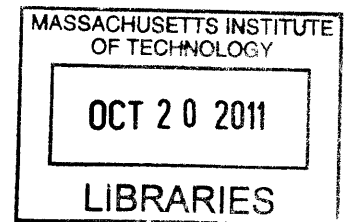
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Massachusetts Institute of Technology

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ABSTRACT

This thesis explores a new strategy in developing products quickly, cheaply and efficiently, with the hopes to redefine the paradigms behind the product design process. This was carried out through the development of the product “flatRat”, a commemorative MIT novelty ring. With this product, we explored different prototyping techniques, manufacturing processes, and business strategies with the hope to optimize the process for others to carry out similar projects. This thesis summarizes a selection of work from the development of flatRat from concept generation to final product sales.

The ultimate goal of this project was to bring a product to life with limited resources. From the project’s beginning in June, 2009 to its capstone in February, 2011, flatRat was designed and developed fully into a marketable product followed by an initial manufacturing run of 500 units. These were sold to MIT’s Class of 2013 Ring Committee and given away to attendants of the “Ring Premiere” Ceremony on February 11, 2011. This product is currently being developed further to be sold at the MIT Museum and Campus Bookstore. The process developed around this product is currently being implemented at Olin College of Engineering under Dr. Lawrence Neeley.

Thesis Supervisor: Maria Yang

Title: Assistant Professor of Mechanical Engineering and Engineering Systems

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ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge the influence of my two project advisors Prof. Maria Yang and Dr. Lawrence Neeley. They were both invaluable resources to both the thesis project and my development as a designer and engineer. Their continued involvement and excitement has been the backbone of this project and I will always be grateful for their help.

I would also like to acknowledge the work of Paul Uche '13 who assisted with a almost every aspect of the final production of flatRat. His involvement was a tremendous help and made the thesis a true success.

Lastly, I would like to thank MIT's Department of Mechanical Engineering who funded this project for the past two years along with providing the facilities to make it possible.

Introduction

There are a multitude of product development strategies being implemented throughout industry, all with the hopes of bringing profitable ideas to market. An idea usually needs a considerable amount of money, time and man power to fully develop itself from a promising concept to a profitable item. There are exceptions to these standards, but most products on store shelves are backed by large amounts of money with vast resources for prototyping, marketing and distribution. This leaves a significant barrier to entry into the product market to those who cannot overcome the standard cost associated with product development and distribution.

The goal of this project is to develop new avenues that a product can come to life , focusing to minimize time and resources in its development. By doing so, we hope to make the product development process more accessible and allow more ideas to come to market from a variety of backgrounds. We are exploring these strategies via several products that allow us to test our new processes first hand while assessing and optimizing their potential for widespread use. The flagship product of this research project is the “flatRat”, a foldable MIT class ring, also know as the “Brass Rat”. Over the past two years, we have explored a multitude of tools under this concept and it has developed into a complete product we are currently producing and selling. This paper will outline the development of the “flatRat” and highlight our exploration into prototyping, manufacturing, and distribution strategies that will in turn, apply back to a process that makes product development accessible to a wider range of people.

It should be made clear that the goal of this project is not to redefine design process in large companies or for designers that have the knowledge to adequate produce their products, but rather develop new strategies to make product development available to a new audience. There is currently a large population of inexperienced designers that will benefit from a renovated and consolidated design process, which we hope to deliver.

1 Concept Generation

The first part of any product development process is generating a concept. This time is incredibly crucial to the rest of the process and ultimately leads to the success of a product. Most products are derived to fill a user need or fill a user need better than an existing solution. Our products ultimately look to do the same, but the foundation of the process is changed due to the constraints and goals of the project.

Rather than generating concepts specifically around user needs, we focused our idea generation around low cost manufacturing processes. This allows us to control the rest of the process for any idea as long as it fits first within this first manufacturing constraint. If we left it unconstrained, ideas would potentially arise that were out of the scope of our process and require complex manufacturing or assembly. For example, if an idea required complex 3D surfaces it would potentially call for injection molding or some other similar manufacturing process. Though these aren't completely out of reach, they come with a set of potential issues and details that would be overly complex for the initial stages of our project and may be out of scope for the first iteration of our process. That being said, we decided to begin with simple, 2 dimensional manufacturing processes and set boundaries for ideas to only be manufactured in that space.

The decision to limit to specific manufacturing processes gives a good set of boundaries for what a product might be within our process, but doesn't create too great of limits such that new and interesting ideas cannot come out of it. The most important aspect of this decision is that we can control the more detailed steps later in the process, such as prototyping and design for manufacturing. We can then provide adequate instruction and guidance through these controlled steps and avoid the variances that may cause delays and cost money. This also puts the project within scope for our team, allowing us to control one variable at a time instead of worrying about breadth of potential options that we haven't completely explored. By mastering the in's and outs within our initial constraints, we will have a robust process that can handle a wide range of potential products. We can then move to on to control subsequent steps that will then expand the capabilities of our process. After we have complete control over the complete set of skills for one specific manufacturing

process, we can then begin to explore another and master the process involved in that form of production.

Ultimately, we aspire to control a wide range of manufacturing processes such that idea generation will no longer be constrained by production. This would allow a designer to completely focus on a user need and then find the prototyping, manufacturing and distribution path to take their idea through full development, no matter the variety or complexity of each step that may be necessary. This end goal will take a considerable amount of work and time, but by steadily working and mastering each step, a full catalog of potential options will be developed and open to users.

This thesis explores the first of these options with products that are (1) purely mechanical and (2) manufactured by 2 dimensional processes. This means that the form of a product or each piece within a product is determined only by variations in the X-Y plane with a controlled Z. The material will have a set thickness and the manufacturing process will be able to alter the area and shape of the flat plane but it cannot vary the thickness or depth a part. This would be like having a piece of paper that you cut to any shape you want, but you can't make the piece of paper thicker at any point. You may be able fold it or bend it to change the shape but the initial thickness cannot be altered.

This control over the first products is critical for controlling a lot of the primary steps of the development process. Two dimensional products have some pros that allow us to control a lot of the process and also easily transfer it to a wider population. First, the manufacturing processes are relatively intuitive and the tools for designing are all easily accessible. The packaging for these products is also straightforward. With two dimensional products, one only needs 2D packaging which can be as simple and cheap as an envelope. This in turn leads to easy shipping and distribution, with smaller objects being as easy as standard USPS first class mail. These are all in line with our initial goals of limiting time and cost associated with our process along with simplifying our first run.

The constraints take products down to a very simple level and will not only allow us to optimize the steps of the process but we will also optimize how we learn and document these processes for others. The key to the first stage of this project is learning how to assemble information and details about every aspect that may arise in each process. Initially

we planned on this to be a quick and non-trivial aspect but this first run took much longer than expected. Even though we constrained the project to these low level products, we had to learn how to learn from our work and how to translate it into a meaningful process. This was an incredibly important part of the project allowing us to refine how we approached subsequent steps and how they interact. We were also able to encounter most of the problems that arise in these manufacturing or prototyping processes which may help future designers avoid pitfalls in their projects.

1.1 Benchmarking

With these constraints in place, we began our first iteration of our development process in June of 2009. Our first step was to introduce ourselves to the space we were working in by benchmarking current products that used similar manufacturing processes as the ones we were limiting ourselves to. Benchmarking is the observation of current standards among products that currently exist and how they are implemented into the market. This step allows us to get a good idea of what is currently being sold, how far the technology can take us, and what has actually been successful in the market. By collecting all this information, we can further guide our concept generation and optimize our decision based on the details of existing products.

At this point in the project, we had inclination towards laser cutting as a manufacturing process due to our easy access to the machines and its capabilities to prototype within our constraints. As we continued our research in the following months, we expanded the breadth of our scope to other manufacturing but the initial benchmarking efforts were constrained to simple 2D products that had the potential to be laser cut. All products were recorded by name, brief description, and commented on as shown in the spreadsheet in Appendix A on the following page.

As we went through this step in the process, it actually proved to be potentially useful in cutting time off the overall process, which was one of our primary goals. In our case, we're able to learn a tremendous amount from simply exploring the current market and how the technologies are used. For example, Figure 1 demonstrates abstract geometries and

interactions that can be used with the the laser cutter. We could have explored and eventually come to the conclusion that we could make a product such as the elephant skeleton, but it would take a lot of time to get there. By evaluating the market, we saw the products that are using the technology fully and the potential for our product.

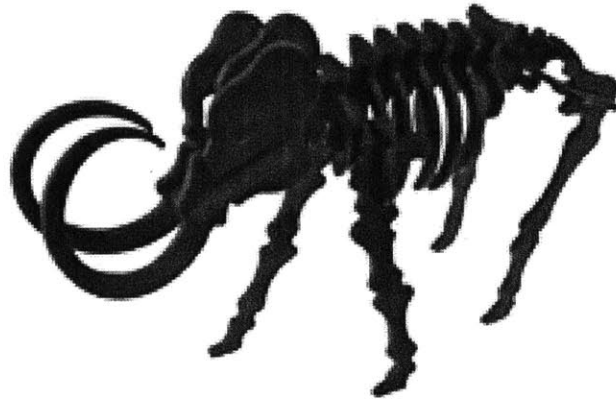


Figure 1 :Laser cut elephant skeleton held together without adhesive. Epilog Laser Company [1]

The benchmarking process also included a basic search for user needs and how some of the products that we observed were filling those needs. There was a particular focus to wallet sized items that were the size of a credit card but also served a particular function. These ranged from complex multi-tools to bottle openers to purely aesthetic novelties, all of which were flat packed to fit in a compact space shown in Figure XX.

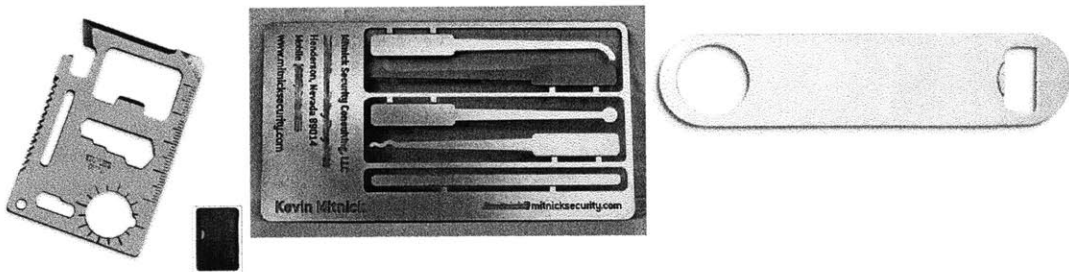


Figure 2: From left to right: wallet multi-tool [2], lock pick set [3] and bottle opener [4]

Another interesting theme of products take 2D pieces and manipulate the final form to become a 3 dimensional product, both functionally and aesthetically. These products were particularly appealing because they offered new potential for our product to take more advanced shapes and functions beyond some of the simpler flat packed objects we observed. Some of the benchmarked products in Figure XXX show the potential for a flat product to be altered into 3 dimensional form.

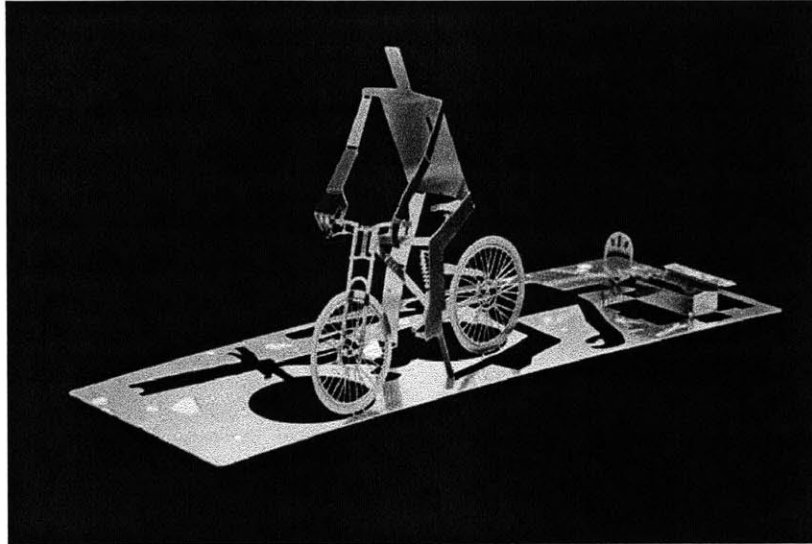


Figure 3 :Mikro Man figure “Off Road”. Begins flat and folds up to figure on bike [5]

The Mikro Man product line, as shown in Figure 3, have based their entire company around this technique. Their initially single flat piece bends into an artistic toy figure.

1.2 Brainstorming

The primary goal of the previous steps is to create a certain level of controlled idea generation within the brainstorming process. By ensuring all the constraints are known and understood, the time spent brainstorming can be incredibly effective in finding a good idea that fits within our specific process. Brainstorming, in product design, is the formal process of generating new ideas. Good ideas don't always come in a single of moment of inspiration, but most often come during an organized brainstorming session that has been set up with a specific set of goals and constraints. These sessions help generate a multitude of ideas that afterward can be filtered to good and bad ideas, and during the evaluation the best ideas

can be down selected to the best solution. This section will review the overall function and strategies of brainstorming while also outlining the results of our own brainstorming session.

The following section is an example of how we might translate this process to people who are new to brainstorming along with giving a basic outline of how our process works in relation to this paper.

Guide To Brainstorming

First and foremost, the main purpose of a brainstorming session is to come up with as many ideas as possible. You may think that your only goal is to come up with one good idea that you can turn into a product , but that isn't the case for brainstorming. Brainstorming allows you to come up with a multitude of ideas that, until the end, should be considered of equal value to your project. Never evaluate your ideas while your brainstorming, just worry about getting lots ideas out. The more ideas you generate, the better chance you'll find a good one along the way and the more options you have when you want to make your final decision.[6]

A brainstorm session is structured in order to promote a multitude of ideas. There are developed rules and guidelines that professionals to amateurs alike use to have the most efficient brainstorming sessions. Most often, a group of people will get together in a quiet and comfortable area to have a brainstorming session. There are established rules beforehand and a set an amount of time to generate ideas. The brainstorm begins with a prompt, and everyone then proceeds to think of ideas, document them, and present them to the group. It is meant to be a fast paced process with ideas flying for however long you have set to brainstorm. To get good results, we have created a checklist for the optimal brainstorm.

Checklist for Brainstorming

Setup

- People - You can brainstorm all by yourself, but studies have shown that the best brainstorming happens with 3-5 people. These numbers allow for easy communication but

also enough brainpower to put out a lot of ideas. They don't have to be people part of your project and sometimes its better to bring in different people to get new perspectives and hopefully new interesting ideas.

- Place - Find a place that everyone can be comfortable and can easily communicate with one another. A wall, dry erase or chalk board are a plus.

- Tools - One of the most critical parts of the set up is developing a universal mode of documentation. Everyone needs to document their ideas the same way and you need to have a way to have all the ideas presentable to the rest of the group. Here are two ways that you may want to do it:

- Paper and Pin Up - Everyone should have a stack of paper and a marker. As you come up with an idea: draw a quick sketch, put a descriptive name on it, give a quick description to everyone in the group, and pin it up so that everyone in the group can see it. It is important that you announce and pin your ideas visibly. First, so that they don't waste their time writing down the same idea if they think of it later in the brainstorm and also that they can potentially build off it into other ideas.



Figure 4 :Paper and Pin Up brainstorming session held during Discover Product Design Program, August 2009

- Dry Erase/Chalk Board and Recorder - In this scenario, one person is designated as the idea recorder. Everyone comes up with ideas, gives a quick description and the recorder writes down a descriptive word or picture to record the idea on the board.

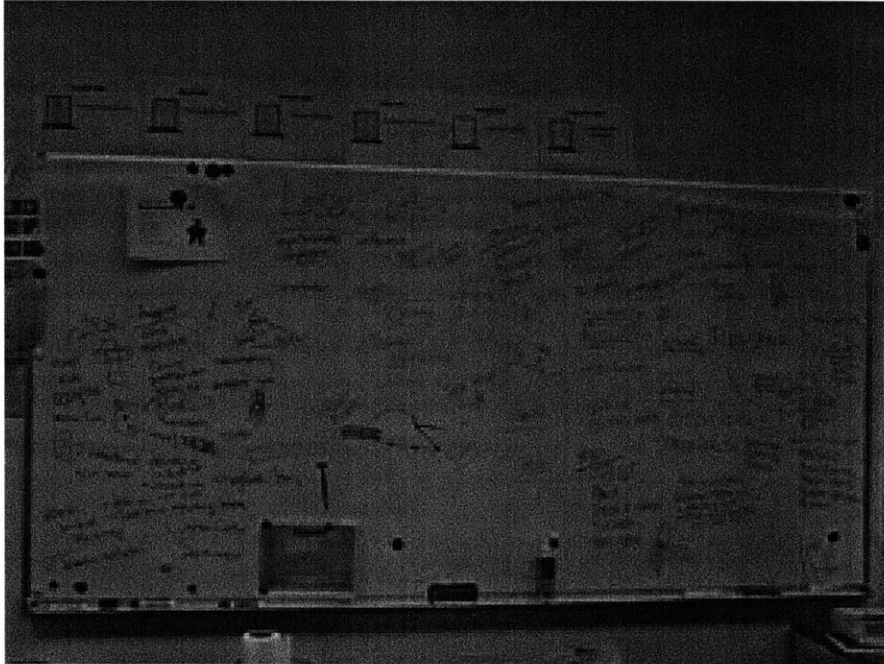


Figure 5 :Dry Erase brainstorm session for flatRat project held June 2009

Rules To Brainstorming

- Establish a set of rules for the session and make sure everyone knows them. This is important to how well your brainstorm flows and the quality and quantity of your ideas. Here is a basic set of rules that should lead to a productive brainstorm:

1. Focus on Quantity - As mentioned previously, brainstorming is all about getting lots of ideas out there. Encourage people to put out every idea that pops into their head.
2. Withhold Criticism - There are no good or bad ideas during a brainstorm, just ideas. Don't waste critical thinking time on evaluating the intricacies of any idea.
3. Welcome Unusual Ideas - Thinking out of the box is key to potentially finding a new and innovative idea. Even if something isn't feasible, there may be aspects of it that will contribute to other people's ideas and lead to something interesting.

4. Combine and Improve Ideas - There is no idea ownership during a brainstorm, therefore you can take someone's idea and build on it or change it to a new and interesting idea

5. Have Fun - This shouldn't be a frustrating process but should be an enjoyable time to thinking creatively and put out a ton of ideas.

- Set a time limit - You should limit your brainstorms to between 15 and 30 minutes. This amount of time is long enough that people can think through things thoroughly but not exhaust people creatively. It also yields a manageable quantity of ideas that you can evaluate later.

- Prompt - You should have a designated prompt to focus what you are brainstorming for. In this case you'll be looking for "2D or 2D->3D products". You want it to be directed but not too open ended such that your ideas are all over the place.

- GO! - Even if you don't have any experience, give it a shot and see how many ideas you can put out.

We set up a brainstorm session to think about potential 2D products made by laser cutter. Everyone who was involved was prepared by looking over the benchmarked products and contributing products to the list that they found. Everyone was given the rules of the brainstorm and the prompt for 2 dimensional products leading to a multitude of ideas as seen in the Figure 5 above.

After our brainstorm, we reflected on all of the ideas and evaluated the results. The first step in this process was to categorize the ideas and focus on the areas that we saw most interesting shown in Figure 6.

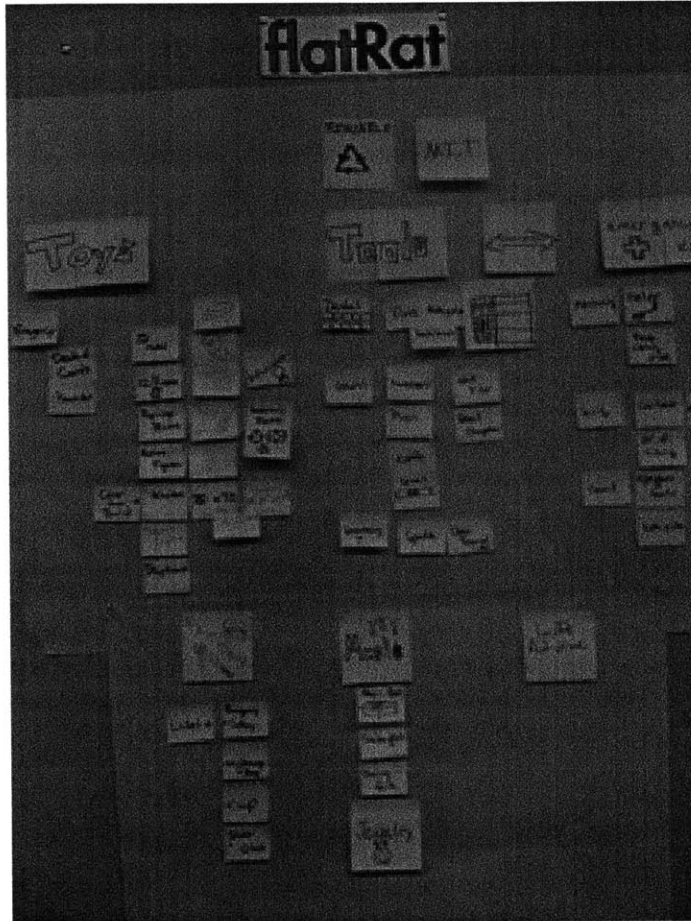


Figure 6 : Collection and categorizing of ideas from Brainstorm in Figure 5

From these results we could then go onto deeper evaluation and begin to down select to a concept that we wanted to go forward with. The ease and success of concept selection directly relates to the ideas generated from these early stages.

2 CONCEPT SELECTION

With a multitude of ideas from the brainstorm, we needed to evaluate each in order to move forward with the project. Unlike most concept selection in industry, this down selection mainly revolved around personal affinity for a concept. It was decided that whatever project I went forward with would have to be one that I was passionate about and would be motivated to continue. All of the other constraints and factors could be figured out, but if it wasn't a project that we were excited about it would have a lot more trouble getting off the ground. Most of the time selecting a concept revolves around market potential, technical feasibility, or cost, but with ours we tried to make it fairly personal. There was definitely consideration into every one of these factors and they did contribute to our final concept, but the over arching factor was our excitement.

2.1 THE "FLATRAT"

The clear favorite of our ideas was the concept of a foldable "Brass Rat", MIT's class ring. The ring could be carried around as a credit card sized insert in your wallet and when the time came, you could take the flat ring out, fold it together, and sport a the 3D ring. The ring had the potential to be made out of paper, plastic and most ideally thin metal to give the same aesthetic as the official class ring.

This concept was the most compelling because of the rich history and culture within MIT and behind the "Brass Rat" ring. The "Brass Rat" has been the official class ring of MIT students since 1929 and has become one of the primary recognition symbols of a MIT graduate. The original Standard Technology Ring depicted a beaver, the school's mascot, on it's bezel which eventually lead to it's nickname the "Brass Rat". Every graduating class of MIT assigns a committee to redesign the ring to be unique to their class. Over the years, the tradition behind the ring has grown and it has become one of the defining elements of all of MIT.

Though the ring changes every year, there are common elements that make the ring recognizable. This includes common images of a beaver on the bezel, seal and dome on the sides, and most recently the Boston and Cambridge skylines. The Class of 2011 Brass Rat is depicted in Figure 7 below.

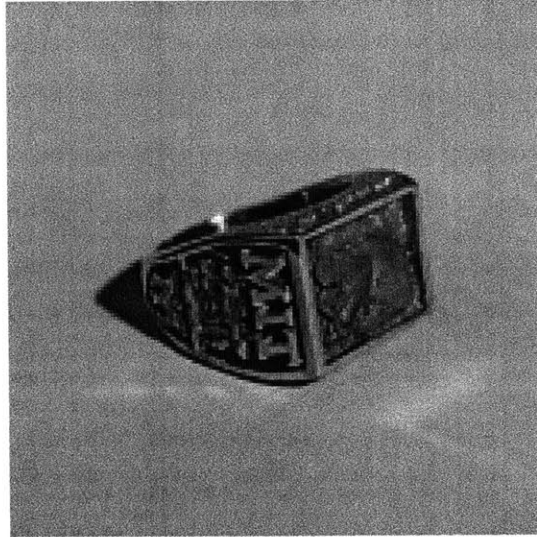


Figure 7 : The Class of 2011 Brass Rat ring

The foldable Brass Rat concept, known as “flatRat” is an opportunity to celebrate the rich tradition behind the ring and commemorate the history of MIT. This product focused on the emotional ties that people had to MIT and their rings, which would make our product a compelling novelty. The actual function of the product is over shadowed by the excitement around it’s ties to MIT culture and community.

One of the most compelling parts of this project was our accessibility to the market. With most products, it is difficult to get your foot in the door with a product and capture a market share. This product however was all within reach with the community that we were working in. I also had a lot of the insight into the market, which would allow me to develop the product with clear information and also the ability to do direct user testing to optimize the design. That being said, there were some major trade offs to the MIT market, mainly in size. We could access it easily but we were also capping the size of the project to the size of the small market of the MIT community. For a student project and my first attempt at product design, this wasn’t as much of an issue but rather was a good fit for my abilities.

Overall, this concept had a ton of potential to go in lots of different directions with numerous pros for its development in our process. The project also played a good balance of ambiguity for what it could become and enough definition that it could thrive within our process. With the concept decided, we began the early stages of prototyping and refining the concept to a marketable product.

3 Prototyping

After down selecting to a final concept, I began to prototype to a final product. The flatRat concept was a great fit for prototyping because the idea was open to a multitude of approaches, forms, structures, and issues that could be hashed out during prototyping. Our initial prototyping processes are extremely cost effective and accessible, with everything being free or within a common household.

Our primary goal in the first weeks of prototyping were to develop as many ideas as possible, with as much spread and diversity among the prototypes that we could think of. This would lead to a wide range of elements that could lead to a breakthrough in the final iteration of the flatRat. Since the first stages of prototyping took relatively no money and little time, not all the prototypes I made necessarily made sense as a final product. Some would be very difficult to use, manufacture or distribute, but they each an interesting element that I hadn't seen in previous prototyping. With low fidelity prototyping, this mindset is incredibly important for (1) potentially finding an innovative solution and (2) understanding everything about the materials and constraints of the prototyping process. By pushing each prototyping tool too its boundaries, we could see what the most extreme prototype of flatRat may look like and how that may translate into an interesting product.

3.1 VISUAL PROTOTYPING

Our prototyping process began with the lowest fidelity tools and advanced to more complex as we felt necessary. The lowest form of prototyping is through sketching or basic digital rendering. Drawing a form, idea or structure can give you pertinent information a very small amount of time put into the sketch. Putting ideas to paper creates a concrete visual for a concept and is the first step to understanding if it can be translated to a tangible prototype. Sketching allows for quick iteration but it also doesn't allow you to understand the physical constraints of the project or the potential issues of the forms represented. It does provide a great first representation and can serve as an invaluable first tool to bringing any idea to life.

The next level above this is digital rendering, which in some forms can take just as little of time as drawing out an idea. Digital prototyping is helpful because it allows the visual

prototype to take more complex forms at a high resolution. For example, I can attempt to draw a perfect square by using a ruler, measuring out exact side widths, make sure the corners are exactly 90 degrees, and try to get it exact with pen along those lines. This will lead to a good looking square, but there are too many potential inconsistencies to make sure that it is perfect. Digital prototyping will take away the human tolerances and make the square precise. It also has the ability to add complex coloring, abstract curves, and is editable after its creation. There are a wide range of tools to use on the computer for this and even the easiest to use can give a great visual prototype for a short amount of time invested. Figure 8 shows a digital prototype of the flatRat before anything was actually prototyped physically.

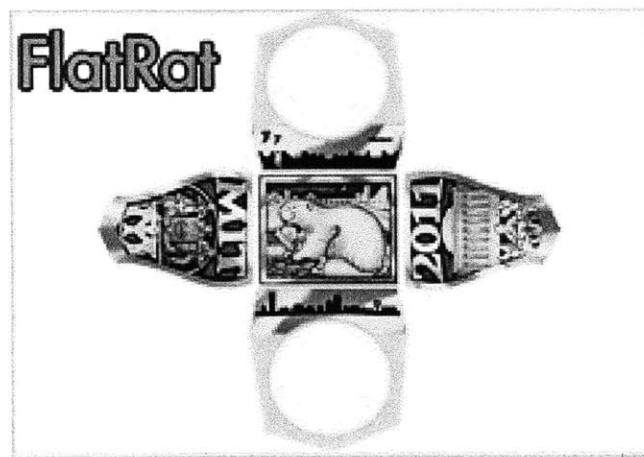


Figure 8 : Digital prototype of flatRat concept created in Adobe Photoshop CS3. June 2009.

Figure 8 was created using Adobe Photoshop CS3 but it's components can all be made by MS Paint or other standard software. I was able to include all the basic form elements of a flat ring while also adding the components of the 2011 Brass Rat to give it a completed feel. This digital prototype gave a quality first representation and would in turn influence future prototypes.

3.2 PAPER PROTOTYPING

Paper prototyping is one of the quickest and cheapest form of physical rapid prototyping. Paper lends itself to many functions and with the flatRat project, paper's properties can be directly related to the materials that we were hoping to use. This form of

prototyping serves our overall projects goals as well. By restricting to 2 dimensional manufacturing, we can essentially reproduce any part with paper or paper based products. Some of the material properties may differ from some of the material options we were considering, like metals or plastics, but all the forms can be modeled and rigid card stock can be used that hold shape to mimic stronger materials.

Paper can be cut and manipulated very easily which allowed us to create dozens of prototypes in a very short amount of time. This process allows for continuous iteration and improvement, which can't be said for a lot of prototyping processes. If we chose to prototype in metals at this stage, each prototype would have a considerably larger investment. This would require us to make more concise prototypes and leave less room for exploration, which was critical in the early development stages of our product. With very little investment, we had huge returns for what we learned in paper and the beginning of our physical prototyping.

The very first physical prototype seen in Figure 9 of flatRat is a prime example of how a low fidelity prototype can prove as a proof of concept.



Figure 9: Rough prototyping of digital prototype in Figure 1. Made out of wax coated playing card. Flat packed form (left) and comparing shape to brass rat (center) on finger (left)

This prototype took less than 10 minutes to make but it yielded a basic proof that the form in Figure 8 made sense as a physical product. It also required no monetary investment by being made out of a recycle playing card.

Continuing on this path of taking a digital design and turning into a physical prototype, I wanted to see what kind of shapes and complexity I could get with the computer and transfer it to paper. With these prototypes, I set a constraint of using only open source computer programs, meaning that they are complete free to download and use. This was in line with our original philosophy of accessibility and cost effectiveness.

The first program I explored was Metasequoia, a Japanese surface modeling program that runs on Windows. It allows you to create and edit objects based on flat surfaces. For example, a cube won't be a solid volume but rather a collection of 6 flat surfaces. This works perfectly for paper based prototypes that can only use a flat surface in order to. The language barrier from its translation is difficult at times, but for the most part everything is universally designed so that anyone can use it. I was able to prototype several three dimensional mockups of flatRat in the software, the first shown in Figure 10.

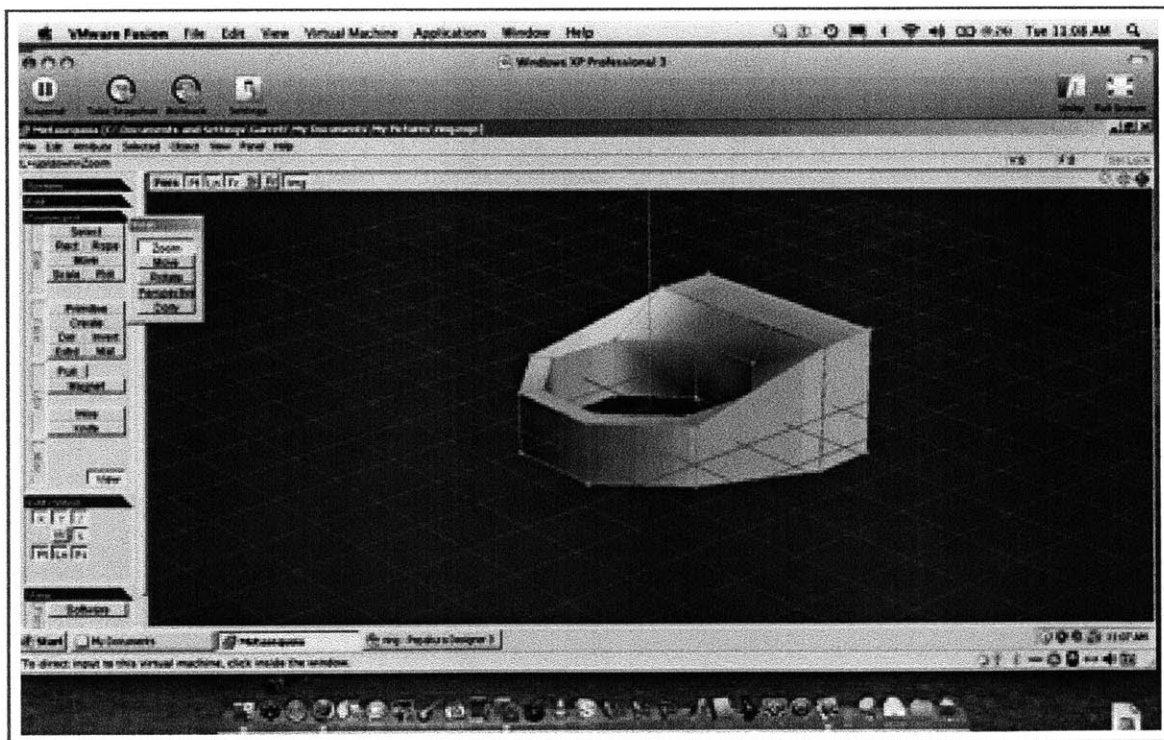


FIGURE 10: Computer aid design software Metasequeria used to surface model ring

This model gave us a good idea of the shape and look of a 3D ring, but a physical prototype would provide tangible feedback for this model. To make a paper prototype, I could have done extensive geometry analysis and precise measuring and cutting, but that would take far too long for the fidelity of prototype we were looking for. Instead, I found the free program “Papakua” (Figure 11) which takes the surface models created in Metasequeria and unfolds them to paper cut outs. So the complex surfaces made in the original model will be folded out, given flaps, and fit onto a standard pieces of printer paper.

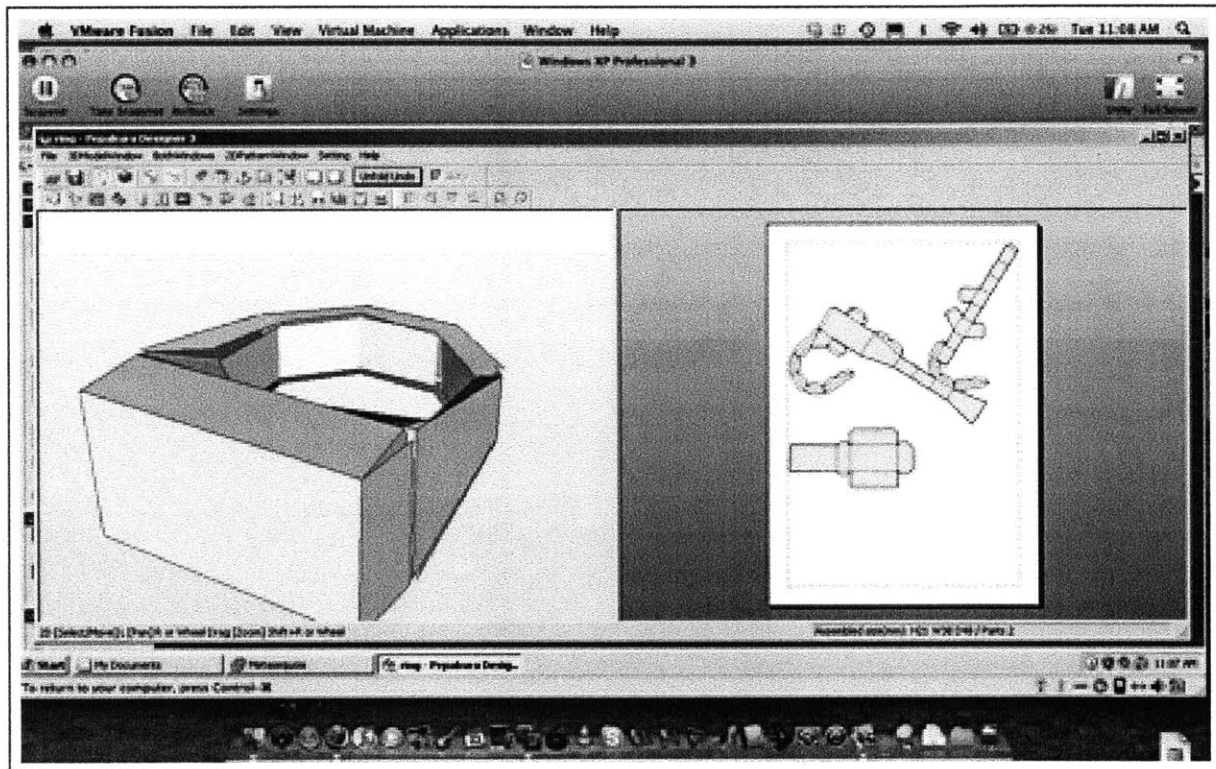


FIGURE 11: Computer aided “unfolding” software Papakura screen shot

I could then print this out onto standard computer paper from a generic printer, cut with an ulfaknife and fold together. This model, shown Figure 12, was fairly complex in geometry and took some dexterity to assembly. This process allowed for some very detailed prototypes that had much more complex of geometries to the point where it was too difficult to reproduce by hand. This also had a great potential of turning into a final form of the flatRat with the ability to fold together a full flatRat with a cheap and easy piece of paper.

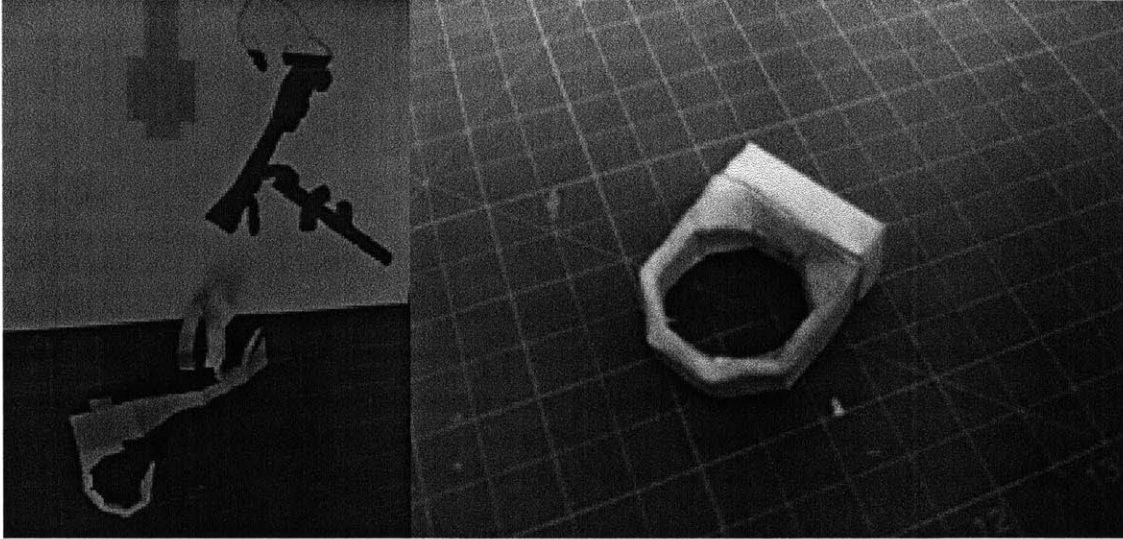


FIGURE 12: Prototype derived from Figure 11 and assembled with paper, ulfaknife and glue. June 2009.

This tool helped create a series of prototypes in a short period of time. Each of the prototypes attempted to have some differentiating factor that would allow us to learn something from each one. The prototypes in Figure 13 is testing the ability to transfer this technology to the size constraints of the rings. These two prototypes approximated a size nine ring and also the ability to include artwork.



FIGURE 13: Small prototype derived from Papakura software with added graphics (left). June 2009.

These two prototypes required an even greater amount of dexterity to assembly. They turned out to look very similar to the Brass Rat look and feel but were pretty hard to put

together, which was a constant trade off that we had to make throughout the process with future prototypes.

The prototype in Figure 14 attempts to diffuse the difficulty of these types of paper prototypes and keep the look and feel of the ring. The ring is broken into 3 components that are individually easier to fold than than the whole ring shown in Figure 4.

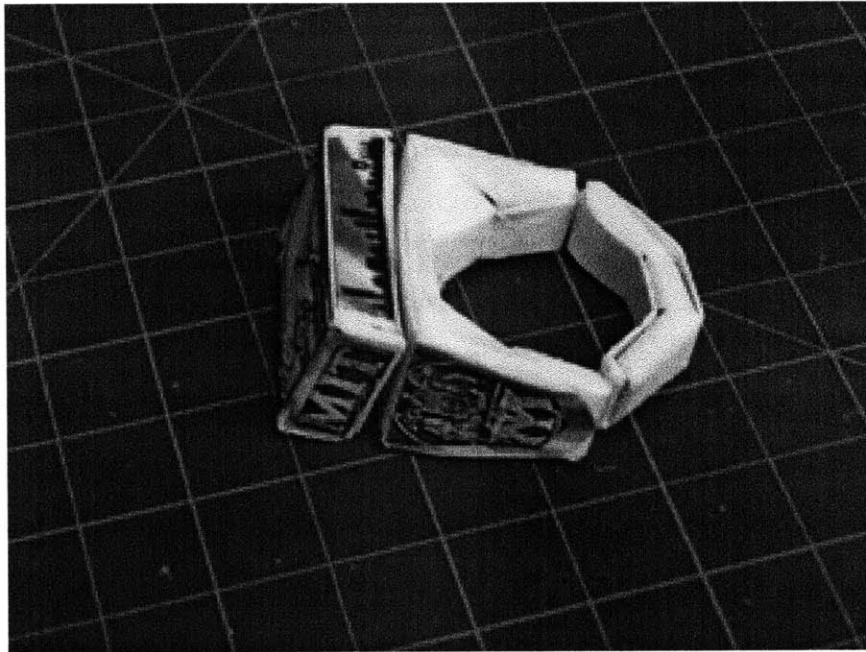


FIGURE 14: Multi piece large ring modeled by Papakura software with added graphics. June 2009.

This prototype was the first exploration into a multiple piece ring. This made each piece easier to fold but several potential issues arose based on the multiple piece component . The most obvious problem was how each piece would interact with one another, especially in the final product. This prototype could be glued together but that solution would be impractical for user assembly. The question continued to be an potential problem for any approach with multiple pieces and would lead to some interesting solutions down the road.

After quickly exploring the multiple part ring, I dove back into creating a ring that would function from a single part. This would help us avoid the connecting issue and also aid in some other factors like keeping multiple parts together in packaging and distribution. I

began to look into different forms that would be replicated if the product would be made out of metal. This would require much simpler folding methods than the previous prototypes but also wouldn't require and fasteners or glue to maintain their shape.

The prototype in Figure 15 demonstrates a paper prototype that would take advantage of the characteristics of metal and also beginning to address the issues of a multiple finger sizes. This ring would be bent to a basic shape down from the bezel, and then points that would meet under the ring would be adjustable. This would allow a large range of fingers to use the same ring and individual sizes wouldn't have to be made.



FIGURE 15: Paper prototype with adjustable flaps for multiple ring sizes. June 2009.

Though this prototype looked to address some of the primary needs, it fell short in giving a good feel. It did however, help stir the issue of multiple sizes and how we were going to address the problem of fitting the ring to many people.

The prototype in Figure 16 continues with the theme of one part prototyping. This is a similar prototype to the previous CAD based rings, but I looked to minimize the amount of material used with the shape. This prototype was considerably easier to fold together than

the previous prototypes and it had a great feel once it was completed. Overall, this prototype had a lot of positives and lent itself very well to the overall concept of flatRat.

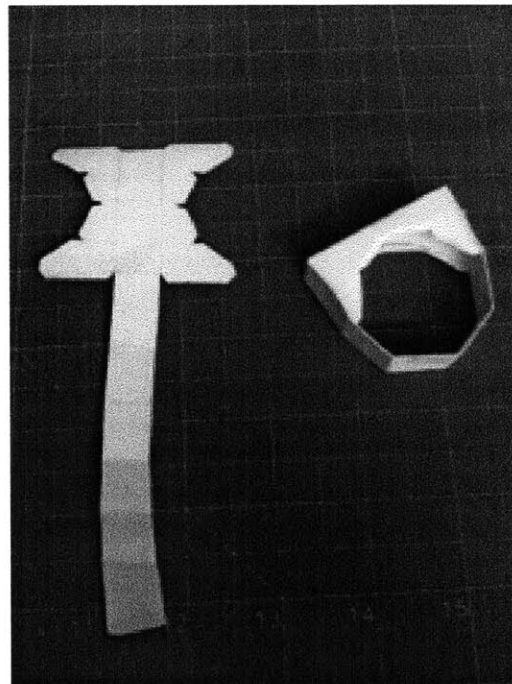


FIGURE 16: One piece prototype derived from Papakura and assembled with glue. June 2009.

The main issues with this part were its size and again, the issue of multiple sizing. At this point in the project, we were looking to fit the entire product in someone's wallet and this prototype was double the allowable length. The issue of multiple sizes wasn't served in this prototype but its form gave rise to a potential solution of changing the band length to change the sizing. The long tail seen in this prototype could easily be shortened or lengthened to fit anyone's ring.

To build upon this concept, my next prototype looked to serve multiple sizing while maintaining the form of the ring. I also began to look more closely at what makes the look and feel of the Brass Rat unique and how to implement those aesthetics with the functionality that we want for our product. One of the most defining components of the ring is how the bezel interacts with the rest of the ring. There is a distinct ridge that borders the main beaver depiction and the inset bezel is a unique feature that people can recognize from a distance. I also questioned some of the form elements needed on the flatRat, in particular needing full form around the bottom of the ring. The underside of the ring is rarely

looked at and if someone is showing off a ring, they exclusively display the top side of the ring with your other fingers covering the bottom side of the ring. With those thoughts in mind, I made the prototype shown in Figure 17 in CAD.

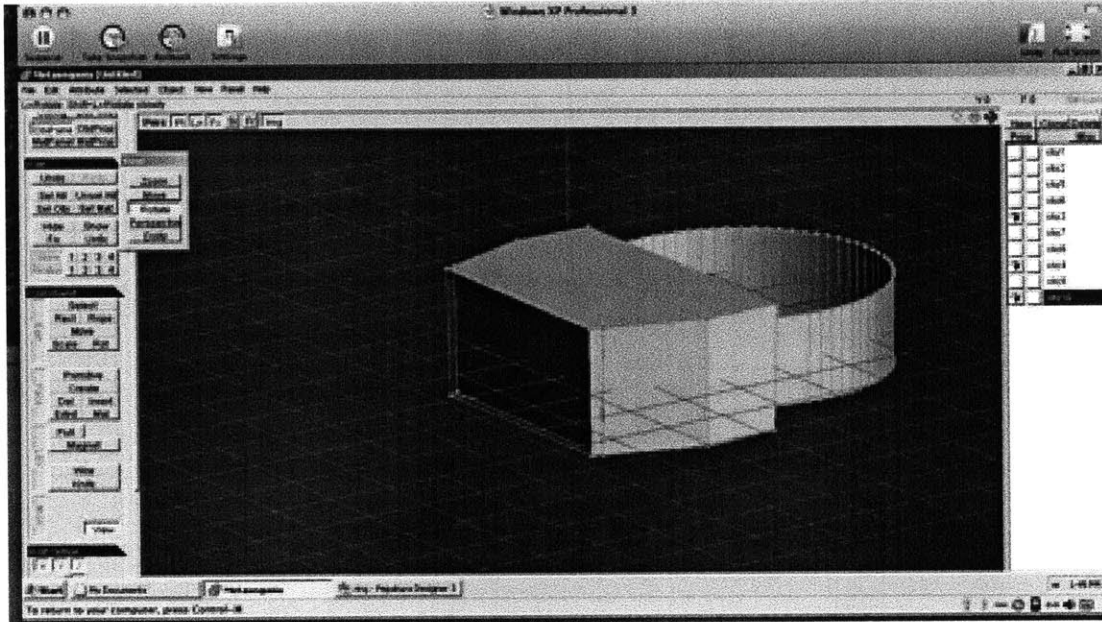


FIGURE 17: CAD of more complex multi piece prototype. June 2009.

This prototype stepped back into multiple pieces in order to gain all the functionality that we wanted. I also emphasized the need for all the surface to be able to display the full artwork of the ring along with the raised ridge bordering the bezel. The full assembly of the ring is shown in Figure 18 from 3 pieces to a comparison to the Brass Rat.

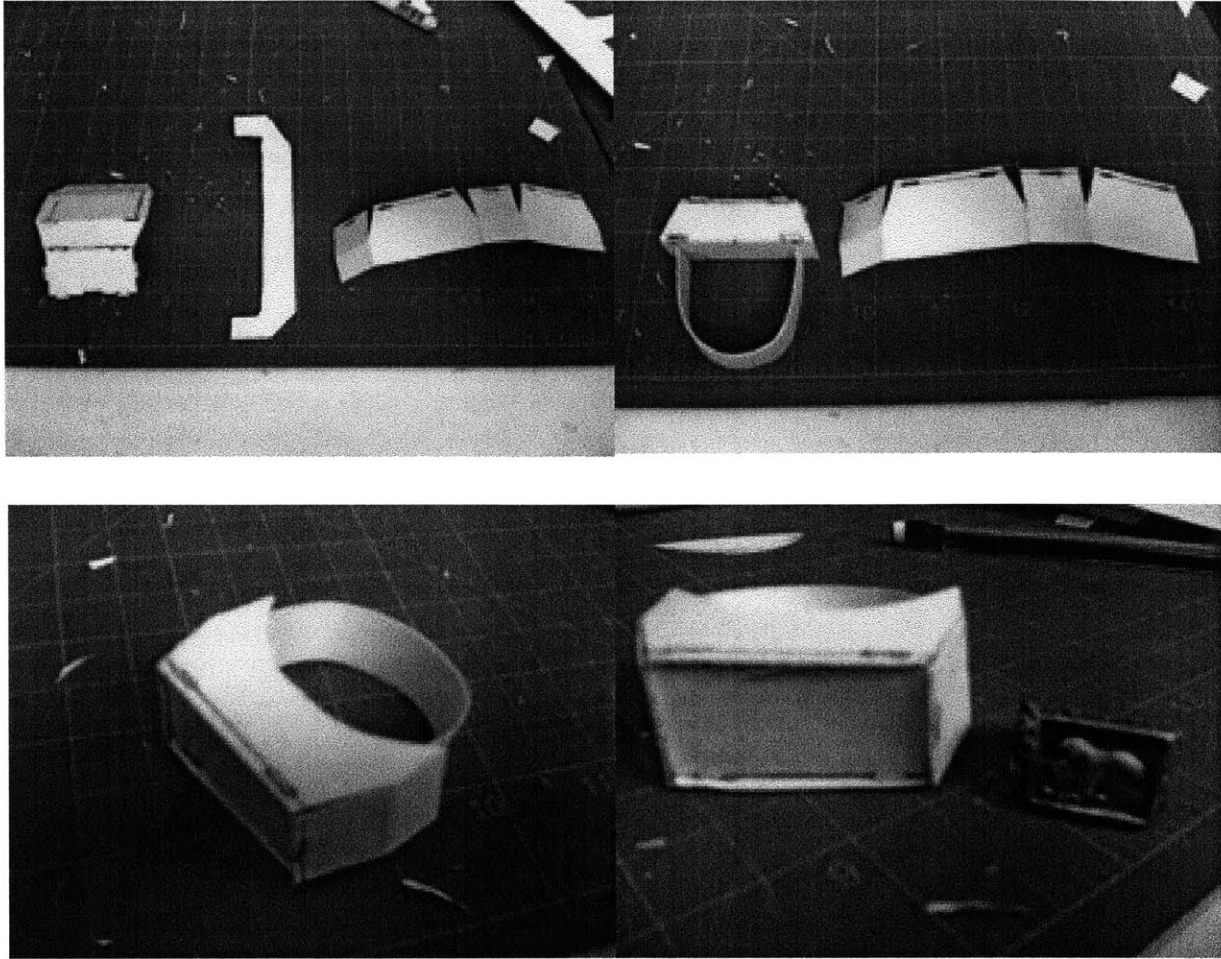


FIGURE 18: Physical prototype from CAD in Figure 17. Product assembly cycle from top left. June 2009.

This top side of this prototype was the most similar to the Brass Rat along with having the potential to serve different size of rings. The prototype requires assembly and each piece is connected strictly by mechanical functions of either hooking or press fits. It met a lot of our constraints, but it had the issue of a large surface area needed for the complete product. Though the bottom side served a primary function, there was something missing about the look and feel of the ring. If it wasn't on your finger, it would look incomplete and unrefined. We were assuming that people would wear the ring for a few minutes, but the rest of the time it would serve as a novelty item that was fun representation of MIT. This brought up the issue of how complete the product had to look and the balance between functionality and aesthetics.

Figure 19 dives into the functional side of this argument by attempting to again satisfy our issues with variable sizes. The basic bezel was fit with a rubber band that would conform to the complete range of finger sizes.

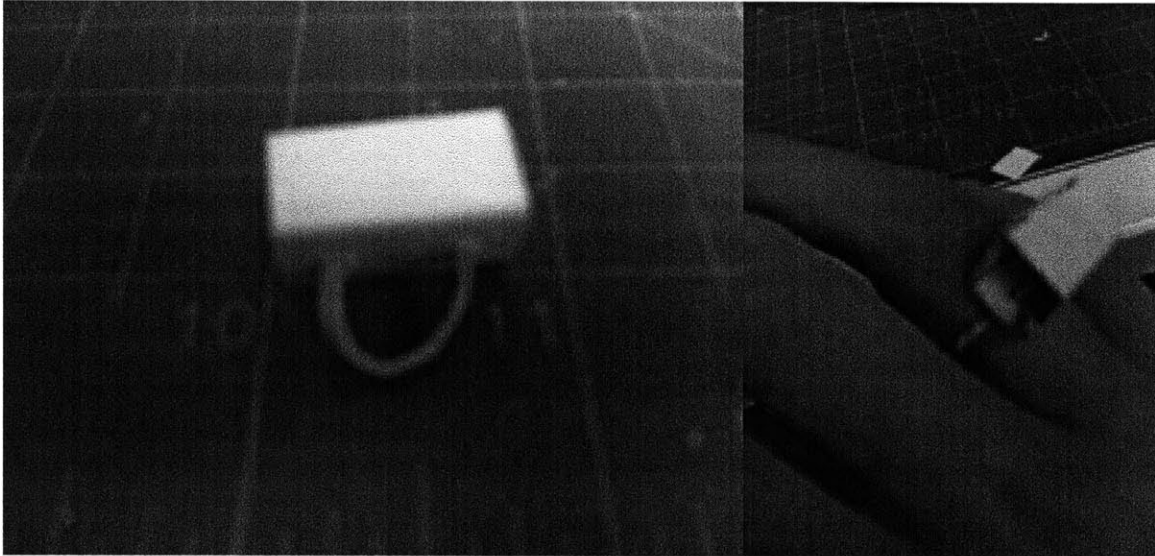


FIGURE 19: Basic bezel and rubber band prototype. June 2009.

This solution was great to include all of potential market with one ring but it also had some big issues with implementation and aesthetics. The biggest downfall of this prototype was how we would be able to implement this function easily within our manufacturing and assembly steps. We would have to source an entirely new manufacturing process and then would have to assemble the product accordingly, or find a way that users could easily put it in place. Even if we did have the users assembly the product we would still have a more complex packaging process that would have to include the multiple forms and materials.

The next few prototypes were an attempt to completely step away from the techniques that I had previously been working with and potentially find a new solution to our problems. Figure 20 shows a quick prototype into foam core, a thicker composite material made of paper and foam. This prototype was definitely difficult to work with and the end product showed the results of that. In order to work with material, our manufacturing process would have to be very detailed and controlled to get quality edging and form. Overall, this quick

prototype gave a quick indication that working with this material would probably be a bad decision.

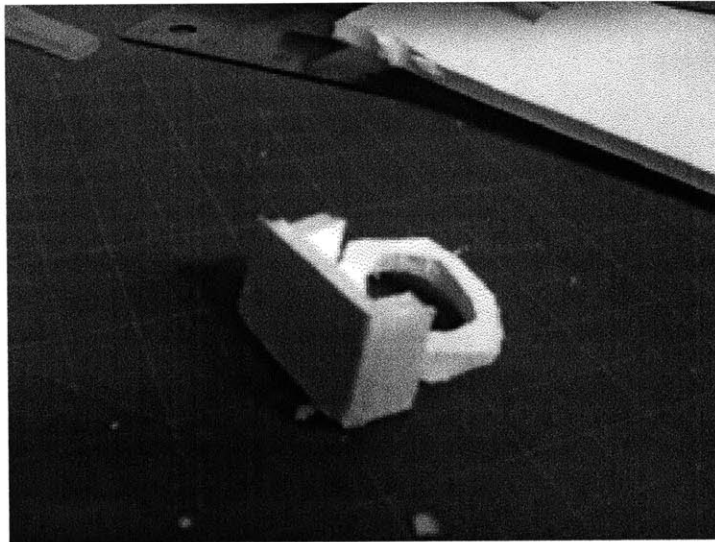


FIGURE 20: Foamcore prototype. July 2009.

On a similar path, Figure 21 is an exploration into 3D materials to see if there was anything interesting to learn from those types of forms. For these prototypes, I carved blue foam to the form of the rings. One prototype was left whole while the other was cut to smaller pieces for potential assembly. This process was tedious and without the correct tools, the prototypes turned out to be pretty rough and unfinished.

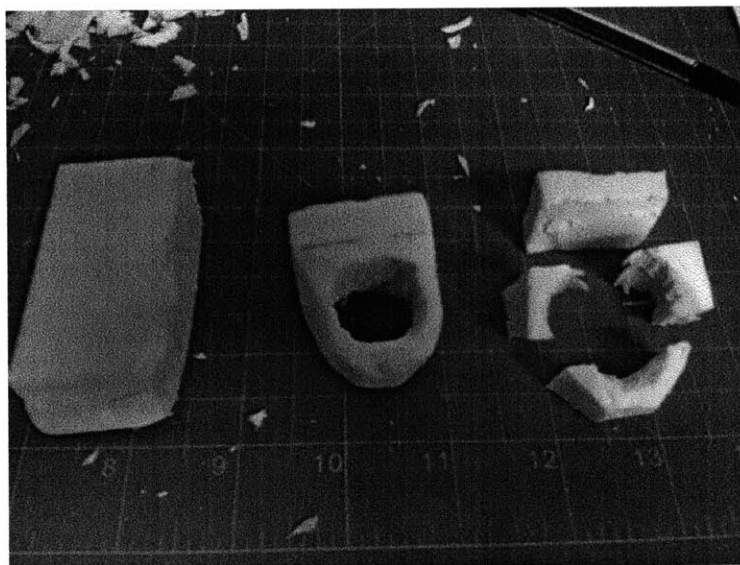


FIGURE 21: Full 3D model shaped out of foam. July 2009

Ultimately, both the foam and foam core were difficult to work with and the prototypes that each yielded were poor. This helped us narrow our potential materials and where I'd focus the next set of prototypes. This also was a quality lesson in exploring different materials within prototyping. By quickly incorporating these two prototyping materials I could easily see that they were a poor fit but also a sense of what kind of projects that might be suitable for the in the future. These two prototypes took very little time and gave me a lot of information, which is incredibly valuable for the prototyping process. These two prototypes really didn't contribute anything to the end project, but served as a great, quick learning tool for the prototyping process as a whole and the focus that lead to the future quality prototypes.

After this divergence, I dove back into exploring paper prototypes. With previous prototypes, I was able to see a lot of how I could incorporate all the aesthetics we may need for the project but there were still plenty of questions involving the best way to attach the functional requirements of the ring. Figure 22 shows an attempt to attach to pieces of the ring mechanically. The ring has two tabs on either end that can be placed through a slot, turned 90 degrees and pulled back down into slots that hold the two pieces together.

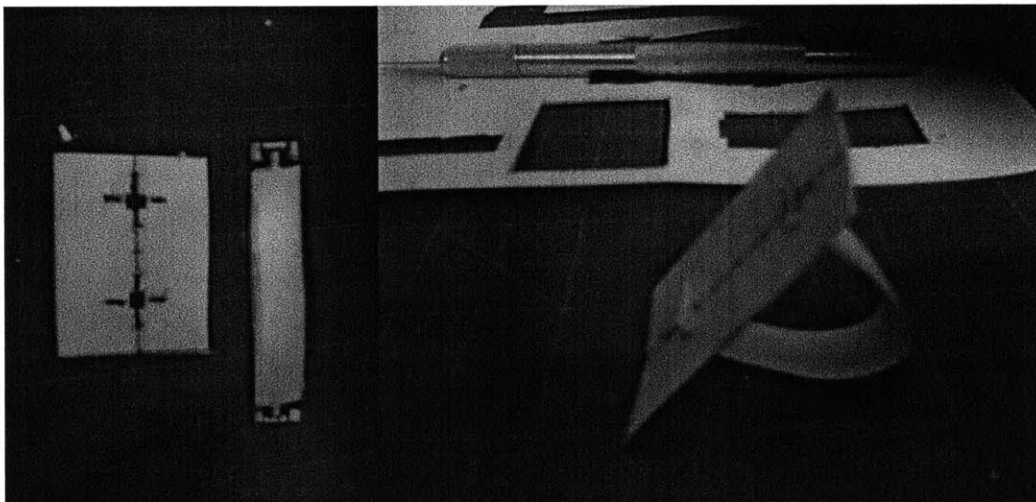


FIGURE 22: Ring locking mechanism for multi piece rings. July 2009.

This prototype started pushing forward to solve our problems with more mechanically complex solutions than simple folding and cutting. These solutions are more robust and can

be done in a multitude of ways to serve all the functions I was looking for in the ring. This solutions isn't necessarily optimized or the best, but it served as a good starting point for the prototypes to follow.

This time frame of prototyping really pushed my creative abilities to think of solutions far outside of the box. By trying to find non-obvious solutions or unorthodox approaches, I started to come across more interesting ideas and more compelling concepts. This started showing the value of repeat prototyping and diversify approaches. With a steady set of various prototypes, each mandated to take a different approach, I was able to see the real boundaries of the process and also how to play within the space to come up with a novel solution.

My next prototype really exemplifies the prototyping process by its unique and non-obvious solution. The goal of the prototype in Figure 23 was to simplify the entire product down to a rectangle. I was only able to use a 90 degree rectangle in order to create a full ring shape. I also wanted it to be a continuous ring that didn't require complex connecting points. This lead to a prototype that would be easily folded and robustly stay together. The prototype when worn would display the shanks and bezel fully and the supporting ring held the rest of the ring together without interaction points.

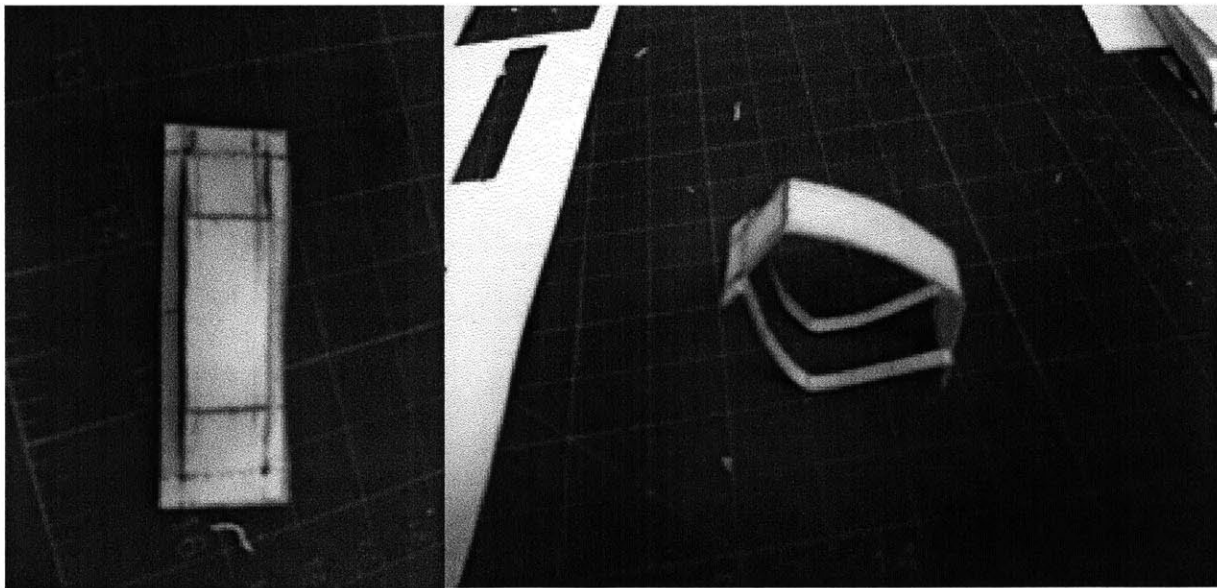


FIGURE 23: Single piece square prototype. July 2009.

This solution lacked in some areas of concern such as a ring look in every component, with an aesthetically lacking underside. This was countered however with the simplicity of the prototype and also the saved cost with the initial form. This prototype, if produced, would be the cheapest to manufacture and would yield a great look and feel. It fits all of our constraints to fit in the form factor of a business card and would be a great addition to someone's wallet. With paper, it has the ability to be refolded and re-worn, something not many of the prototypes have. Though I liked this prototype, I had to continue to diversify and explore to potentially see something new and interesting.

The prototype in Figure 23 inspired to me to push the envelope on simple forms moving in ways that you wouldn't expect. We also had discussions as a group about the potential functionality of the flatRat and the possibility of making it more puzzle like. Instead of using intuitive forms, the product would be non-obvious and challenge the user to put it together the right way. Though the end product still looked to deliver the same thing, getting to the final product would be more interesting and complex user experience. Figure 24 shows my attempt for a puzzle ring that requires some non-obvious folding and interactions that gives both an interesting look and more intricate final product.



FIGURE 24: Complex puzzle ring flat (left) and puzzle ring compared to Brass Rat (right). July 2009.

This prototype was both interesting and insightful. Most of the time, you want to make a product easy to understand and come together with simple and obvious steps. This however, required me to make something more complex and more difficult to user in order to add to the user experience of putting it together. Eventually, we decided this strategy added a little too much complexity for what we were ultimately trying to do, but practice this process and looking to control the user experience in a certain way was very valuable for future prototyping.

Paper prototyping served as an incredibly useful resource and created a great foundation for the project, all while costing less than 5 dollars for all materials used. The value gained from these prototypes greatly outweighed the investment and served as the perfect spring board to the next level of prototyping. It was also all done with tools that anyone can access and use, providing the perfect platform for anyone to use and exploit for our development process.

3.3 LASER CUTTING

Laser cutting is a quick, cheap (for this particular project) and informative prototyping tool. The machines have a wide range of capabilities ranging from cutting surface imagines on materials to creating complex 2 dimensional curves in mechanical products. The laser cutter was our initial end manufacturing process and the constraints of the machine created the initial constraints on our process of 2 dimensional products. This prototyping process served as a great tool for our prototyping by including the detail of computer aided design paired with computer controlled machining. This allowed us to prototype with controlled variations but also consistent repeatability that we would need for future manufacturing.

A laser cutter works by controlling the power of a laser to a single point and being able to move that point over an x-y plane. The concentrated energy in the laser is focused to point on a material and the energy separates the molecules within the material.. This separation, when done so through the entire thickness of the part, is called a vector. Vector cuts can be complex shapes on the x-y plane or cut holes on the interior of a flat part. The power of the laser can be limited so only the surface of a material is altered, which is called

a raster. This effect can be used to add images or basic functional features that require basic multiple thicknesses. Raster cuts have a great amount of variability however, and shouldn't be relied upon for tight tolerances.

Just as paper prototyping, all of the initial pieces must be 2 dimensional. When designing 3D products with the laser cutter, the object should only consist of 2D flat planes and then assembled into the 3D product. This again brought up the issue of interacting pieces and how to design the connection points which will be discussed further in the paper.

The use of the laser cutter requires some more advanced computer programs in order to translate designs into the laser tool paths. The major requirement is a vector editing software, such as Adobe Illustrator or CorelDraw. The program must be vector based, which means it develops an image based on a set of equations rather than pixels. For example, when you draw a line, a vector creates an equation for that line to exist rather than a pixel based software would simply color the pixels in the path a different color. This allows the line to be edited after being created along with creating an equation that can be translated into the laser's movement when cutting.

These programs only allow you to edit 2D parts from a top view and you can't develop the more complex 3D products that the project may be looking for. In order to edit these parts, I used solid modeling software "Solidworks" which can control the thickness of the parts and the interaction between the parts can be modeled. This program has the versatility to create complex assemblies for more advanced prototypes that we couldn't get with vector based programs.

Using both Solidworks and Adobe Illustrator took a specific process in order to translate the files into data that could be used for the laser cutter. Appendix B outlines the necessary process to get the files from these programs to final cut on the laser. There are some portions of this step by step process that can cause issues within the final cuts so by creating a defined set of steps, one can always easily cut files from these formats. It is also possible to cut from many other formatted files as long as they can be opened with CorelDraw for this particular laser cutter.

For more advanced prototypes and to limit the use of glue or other fasteners, I developed a way to snap together pieces with flush edges. This is done with a pressure snap fit with a hook shape on one piece, with ridges to snap into on the other piece. These snap fits can be used for 90 degree joints. This doesn't mean the object is limited to right angles, but there must be a 90 deg angle where the two pieces meet one another.

A basic design diagram is given in Figure 25 with relevant dimensions. The raster areas will require testing based on the quality and strength of the laser cutter that is used in order to get a .005" deep raster cut.

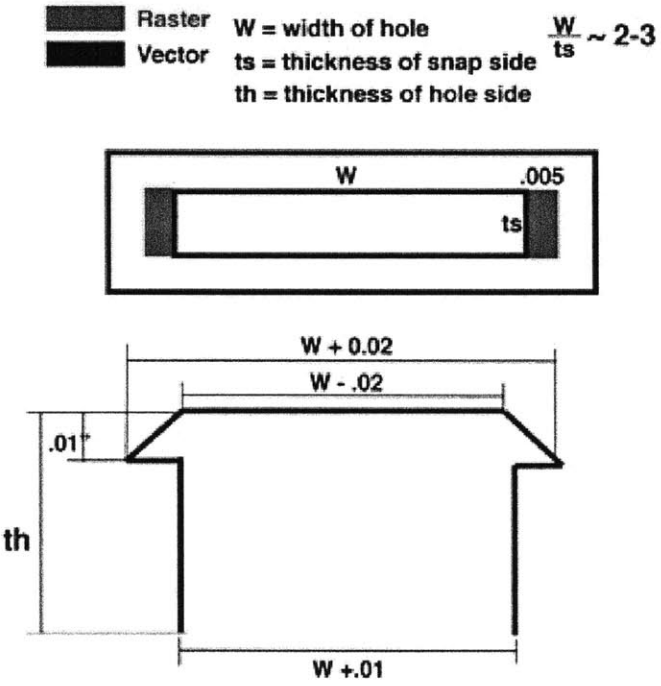


FIGURE 25: Acrylic snap fit feature for laser cut prototyping

These snaps can be used individually but are best when used in pairs. In order to use a pair of snaps, set up the centers of of the snaps to align with their matching hole/snap as shown below.

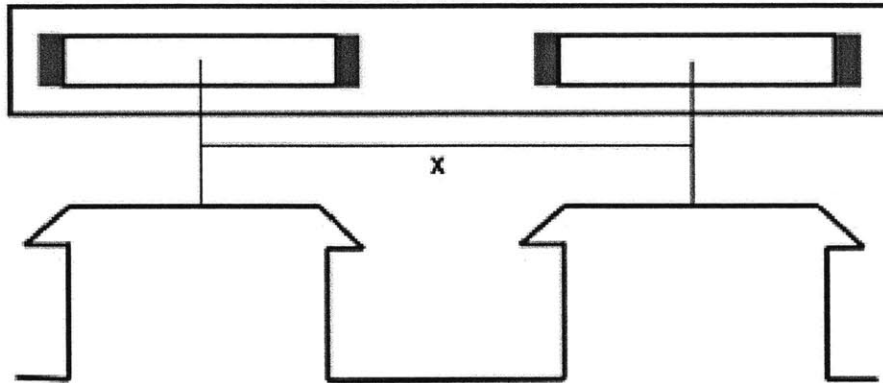


FIGURE 26: Acrylic snap fit alignment for multiple features

The holes can also be used to get a completely flush corner by moving the features to the edge of each piece. If the tolerances from the machine are tight enough, these edge holes will be robust for most applications but have more potential for falling apart.

A plus to laser cutting is that you are able to create images by way of rastering. This can create a binary image, which means there can only be two different levels of contrast. This means your image is created with a series of cuts that are all of the same depth. Some lasers have the potential to differentiate rastering thicknesses for a more detailed depth profile in an image, but none of our testing included these features. There is a limit to the complexity of the images used, but by adding images by laser saves a secondary manufacturing process to add graphics.

3.4 LASER PROTOTYPING

Prototyping flatRat with a laser presented unique challenges for the form and aesthetic of a ring. The first prototypes were bulky and a far way off from a real Brass Rat look and feel. This was a result of the plastics that we were using and their lack of dexterity for this application. After exploring with the basic functions of the laser and getting the basics of a snap fit to work, I produced the first iteration of flatRat in plastic as seen in Figure 27.

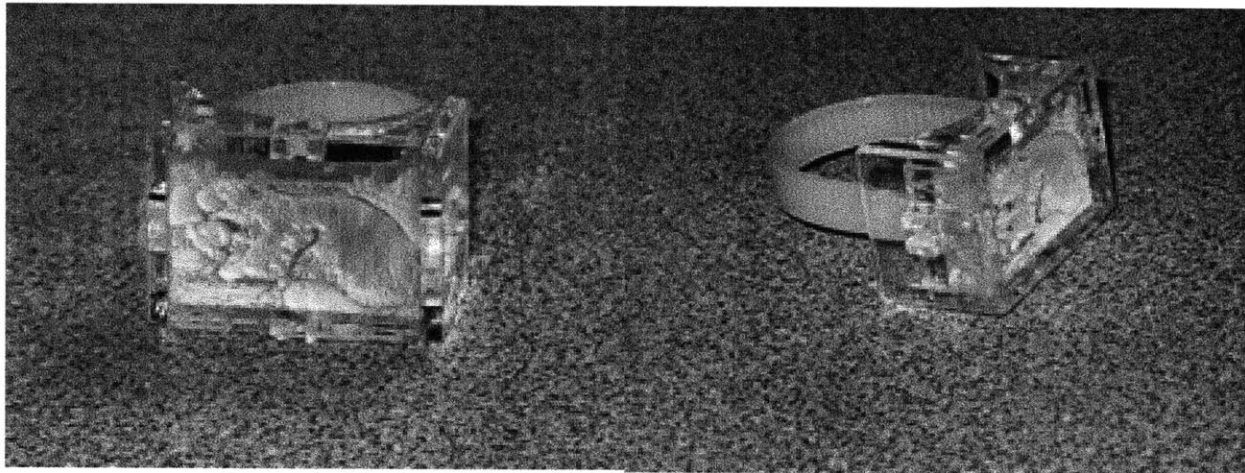


FIGURE 27: Acrylic multi piece prototype with adjustable band and rastered bezel images. July 2009.

This prototype is a total of 8 pieces that are easily assembled and fit together to be a wearable ring. It is primarily made up of two different thicknesses of acrylic sheet and the band is a nylon strap. The strap can be adjusted to multiple sizes of finger and easily fits within holes on the underside of the ring. There is also rastered image of a beaver on the bezel to test to capabilities of translating an image to the ring. The prototype fit a lot of the functional requirements of the ring and with a better color of acrylic, it would start looking a bit more like a real Brass Rat.

As we started to increasing fidelity of prototypes, there was a rising problem of how we were going to package all these pieces. For this prototype, I developed a laser cut packaging solution as seen in Figure 28.

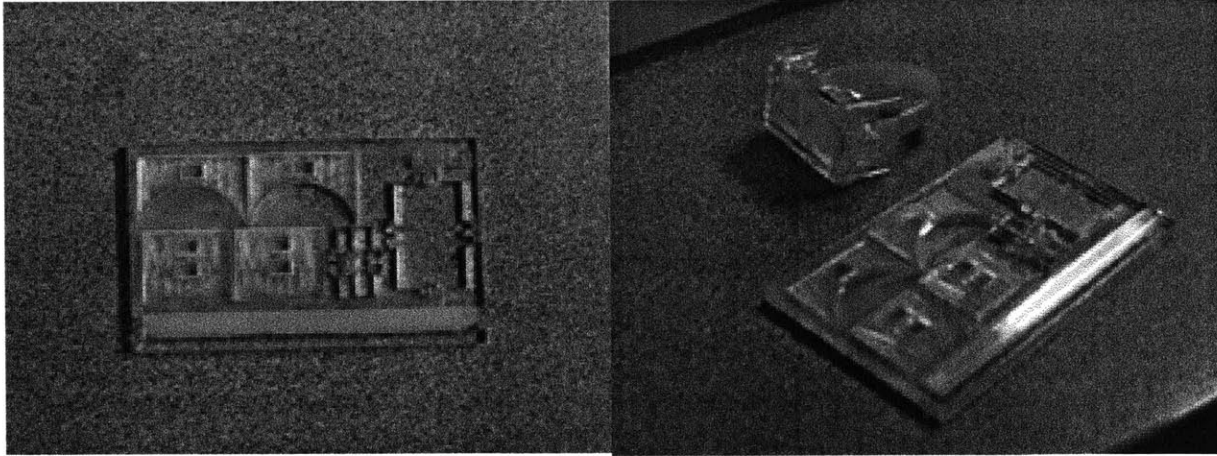


FIGURE 27: Packaging prototype for Figure 26 ring. July 2009.

Since this prototype was 8 different pieces of varying thickness, I had to come up with a solution that accommodated that. The package is made up of the thickest piece of acrylic with those components directly cut into the sheet. The rest of the sheet is rastered half way through in order to nest the remaining components. The entire package was then sealed with clear tape coating to hold everything in place. This solution seemed interesting but it also had some major problems that called for refinement.

The main issue with this prototype was the multiple sizes of acrylic and different material for the band. This would require (1) multiple sources for materials (2) advanced assembly that would take time and money. Though these could all be made on the laser cutter, the whole process of nesting several parts and sourcing assembly would potentially increase cost to the point where we couldn't see any. This prototype also took a lot of time per part to make on the cutter. With the heavy rastering in the material for the nesting parts, each unit would cost too much to actually outsource. Ultimately the product needed to be slimmed down, reduced part count and aesthetically refined.

One of the more difficult issues with the laser cutter was getting quality images with the rastering. Figure 28 shows some explorations in imagine application strategies with different materials.



FIGURE 28: rastering testing on acrylic mirror (left), opaque acrylic (center) and backside rastering on clear acrylic (right). July 2009

One of the major tactile factors on the real Brass Rat is the depth and profile of the beaver on the bezel, so I did my best to replicate that in the initial prototypes by rastering on the top side of the acrylic. This would give a rough surface and basic depth to give a similar feel. This however, would require very deep cuts that would at times start melting the surrounding plastic, leaving a dusty residue and burn marks. In order to mitigate this problem, I optimized the boundaries of the raster on the laser I was using. This was part of a trade off of aesthetic feel and time per cut. With deep cuts, the machine would take a lot longer to lay a depth heavy image compared to a quick cut image that may lose some of it's appeal.

I attempted to find some new solutions among different types of acrylic and different application of the laser. The first was a backside cut on the translucent plastic which shows the image of the ring through the clear plastic. This gave a clean topside view but also took away from some of the look and feel we were going for. I also tried top side cut on opaque acrylic to see how the different contrast would help the look. The image came out clearer due to the dust residue after the cut but could be wiped away and the image was very

difficult to see. The last was cutting an image into a mirrored back piece of acrylic. This acrylic is covered in a reflective paper that shows through the translucent acrylic and gives a mirrored look. By rastering the paper, the image would come out clear with a much shorter cutting time. There was however some difficulty getting consistency with the cut along with easy burning of the reflective paper.

In general, producing a quality image on the ring was very difficult. The constraints of the laser made it tough to get a good look and tactile feel, but some of the solutions were good enough to get our basic prototyping aesthetic across. I started looking into some other secondary processes like screen printing or painting to get the images on the ring with the hope to find an interesting solution to this dilemma.

The next set of prototypes looked to redesigning our system for addressing multiple finger sizes. Figure 29 shows the same ring design altered to fit three ranges that covers 95% of the current population. Ring's were sized a 6, 9, and 12 or small, medium and large respectively, with the hope that people could buy the ring that was slightly larger than your size. This was justified by the user's time actually wearing the ring. If a user only wears the ring from a couple minutes to at most a half hour, having a ring slightly larger would be acceptable. The rest of the time would be enjoying the ring as a novelty. This allows us to tool and stock 3 sizes instead of 24 half incremental sizes that most rings are sold in.



FIGURE 29: Large, medium and small sizes for acrylic ring prototype

These rings along with a more refined form, also reduced the total part count from 8 to 5. There were still two different thicknesses of acrylic but the nylon strap was removed which takes a considerable additional cost out the product. As this prototype developed, we began to explore some different materials for the bezel including the mirrored acrylic and opaque colored acrylic as seen in Figure 30.

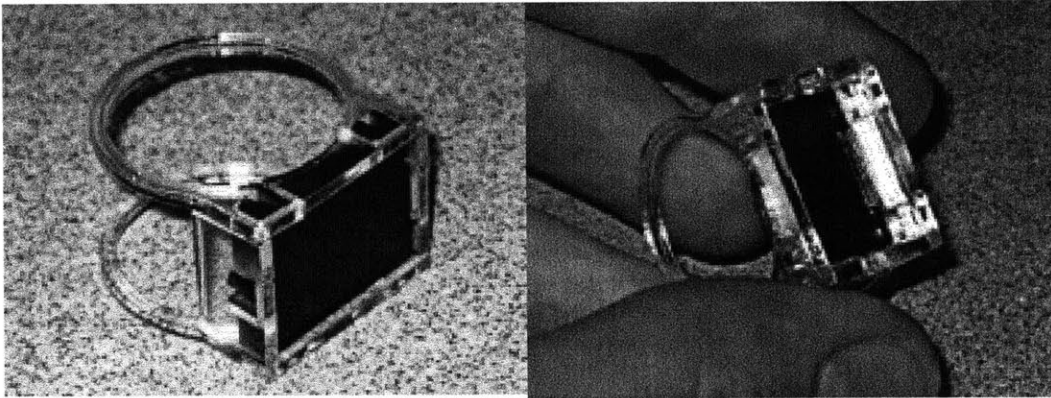


FIGURE 30: Incorporating opaque plastic (left) and mirror acrylic (right) into ring prototype. July 2009

As I prototyped, the team thought it would be fun to explore what a giant Brass Rat would look like and the novelty of having more of a desktop ring as seen in Figure 31.

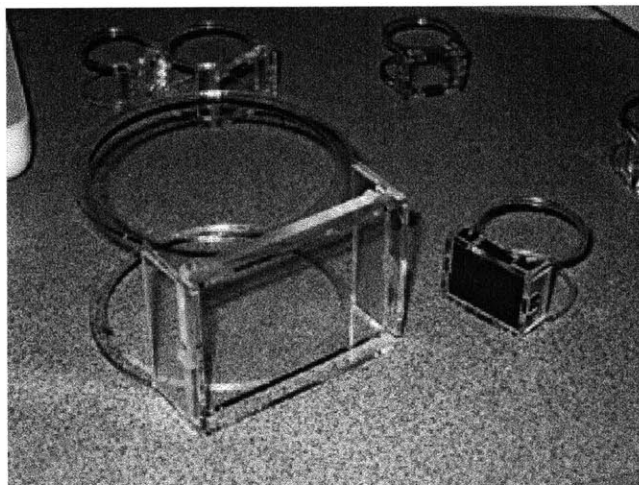


FIGURE 31: Extra large version of ring prototype for desktop novelty. July 2009.

These prototypes allowed us to develop a lot of little concepts with a simple form, but there were still some fundamental issues that need to be resolved with the form and aesthetic. This prototype would stick out when worn and really didn't have the full Brass Rat feel that was wanted. The bezel appears too squared off and didn't flow well between the bezel and the rest of the ring. This was especially apparent in the smaller rings where the sizing of the bezel over powered the base of the ring. The next set of prototypes looked to really attack the form of the ring and try to bring more of the spirit of the Brass Rat into a plastic flatRat.



FIGURE 32: Reformed ring prototype to more closely resemble form of Brass Rat. August 2009.

Figure 32 shows a first attempt at finding a form factor closer to the Brass Rat. The shanks of the ring were angled out and the snaps to the top bezel piece to the shanks were removed. This led to the hole and snaps to the sides to be moved lower and flare out on the edges, which was a bit awkward and bulky. The biggest difference was in the transition from the bezel to the lower parts of the ring, which became much smoother and much more Brass Rat specific.

Building on the foundation of this prototype, I immediately reworked the design and developed the prototype seen in Figure 32. The biggest improvement in the new design is the connection between the ring sides and the shanks, which instead of a snap and hole

mechanism was replaced with a dove-tail like snap system. The alternating posts snap together to give a clean and strong edge to the ring and gave more versatility to the form. The lines and curves of the ring were modeled heavily after the ring and as seen in Figure 33, it began to resemble the Brass Rat profile.

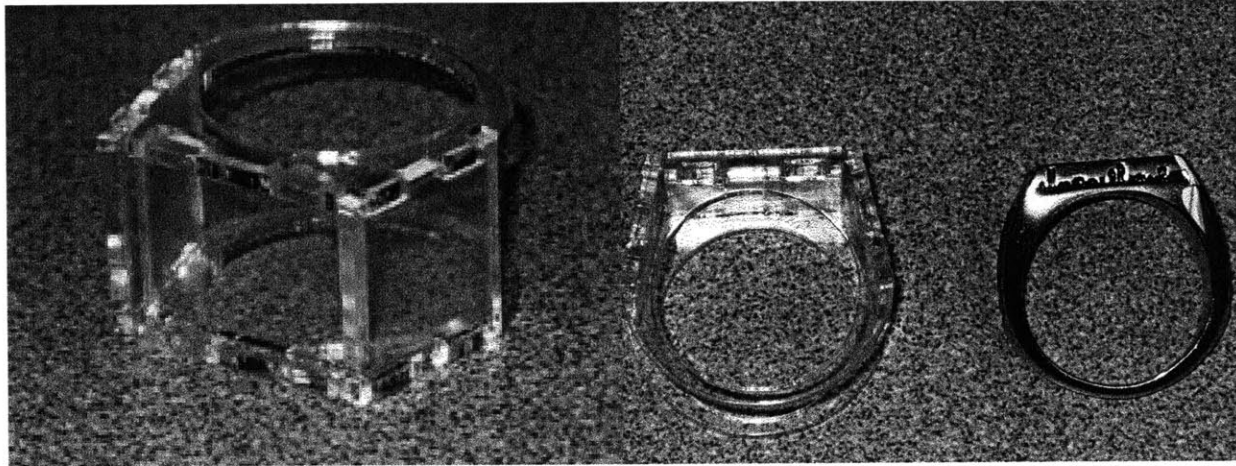


FIGURE 33: Reformed ring prototype with new snap fit edges. August 2009.

This prototype was definitely the best yet and gave the most potential for a viable product. It was also designed to be all one thickness of acrylic so it could be packaged in the same sheet it was cut, removing several steps in the manufacturing and assembly process. Figure 34 demonstrates a mockup of this prototype to be complete cut as one piece on the laser cutter.

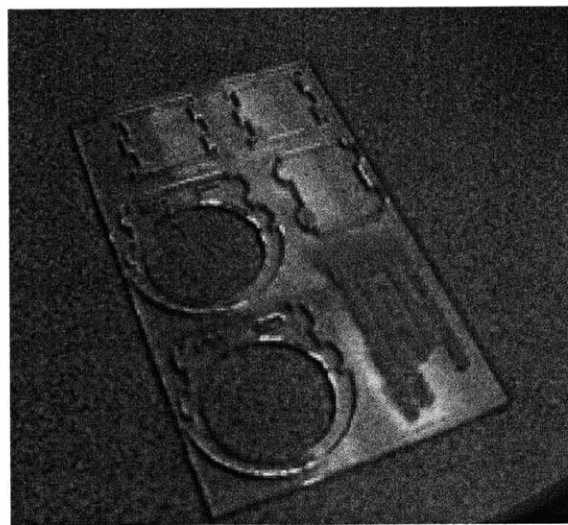


FIGURE 34: Packaging mockup up of prototype in Figure 31. August 2009.

The pieces are held in by small tabs connecting the large piece to each piece of the flatRat by simply leaving uncut portions around the circumference of each piece. The card is similar thickness and size to a credit card and could easily fit in anyone's wallet or pocket. This prototype gave all the functionality, looks and manufacturability that the project was looking for. The only question was whether the laser cutter is ultimately the best strategy or if we even wanted the product to be in plastic. As we continued exploring, we found that it proved to be very expensive and lower quality than what we could achieve.

4 CHEMICAL ETCHING

4.1 DESIGNING FOR CHEMICAL ETCHING

Chemical etching is a 2D manufacturing process that uses chemicals to remove specific areas on sheet metal in order to create complex forms that would be difficult to machine. It begins with an art proof with a desired image or part. This image is then translated to a protective film and where the image designates there will be a hole in the protective film. This film is then put over the desired metal and then put into a chemical bath. The chemical will react and dissolve the metal at all the open areas of the film. The result is a metal sheet with the art work imprinted onto it.

There are a few options when creating the artwork for chemical etching. You can etch on the front of the sheet, on the back, or etch all the way through. Depending on the thickness of the sheet, there are limits on the resolution of the artwork due to isotropic properties of the etching process. Isotropic etching means that as the chemical dissolves down from the initial film layer, it also etches laterally that affects the resolution of the etch.

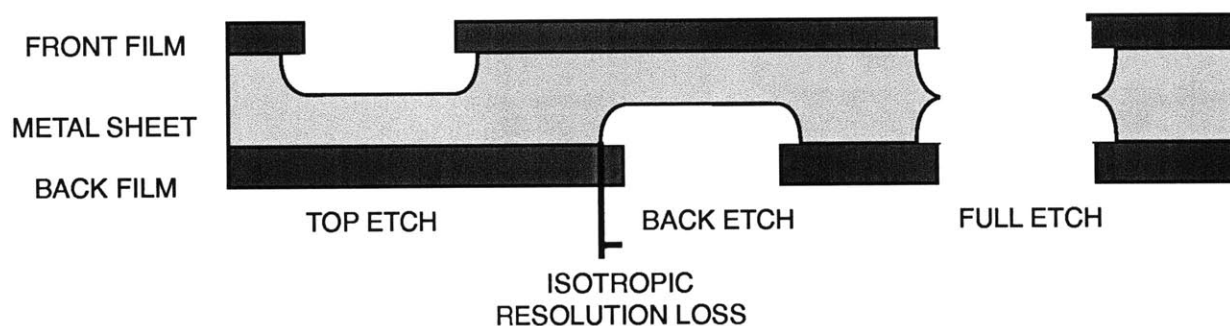


FIGURE 35: Section view of chemical etching process for back, front and full cuts on metal.

Due to the capabilities of the process, the artwork is essentially limited to “black and white” meaning that either you have a mark or you don’t. All complex images must be broken down to two tones, there is no in between “grey”. It is also difficult to use both sides of the a sheet for imaging the same area. If you have a front etch on one side, you cannot have any etch on the back or it will become a full etch through. Essentially, you are cutting half way through on either side and when they overlap it etches all the way through. Below is an example of how this was used to develop artwork on a stainless steel business card.



FIGURE 36: Chemically etched business card for MIT Mechanical Engineering

As you can see, everything on the card is either etched (matted grey look), etched through (“MECH”), or unetched (polished areas). There are several techniques that help make more complex and interesting images with only using these three depths of cut:

- Etching Artwork - You can simply etch the vectors of your images or text directly in. It gives the cleanest and highest resolution lines. On a 0.01” thick sheet, all vector lines must be at least 0.5 pixel width.
- Etching Background - As seen with the three pillar logo, the artwork is raised from an etched background. This gives a “popping” look to the artwork and the matte finish of the etched background gives a good contrast to the card. All raised artwork must be 1 pt width.
- Full Etch - Full etching, as seen with “MECH”, cuts the artwork all the way through the sheet. It is important to maintain structure when creating full cuts, because if the art is too complex or you have surrounded an area in full etching, it will fall through and you won’t get the desired outcome. Lines that are smaller than 1 pt. between two areas of full etching will be lost and all “islands” surrounded by full etching should be supported.

In order to develop the artwork for this manufacturing process, I used Adobe Illustrator. It was perfect for creating vector based images which are required for the manufacturer to

translate what you want into films. Below is an example of translating artwork into vector format and the result:

1. The MIT Mechanical Engineering Logo

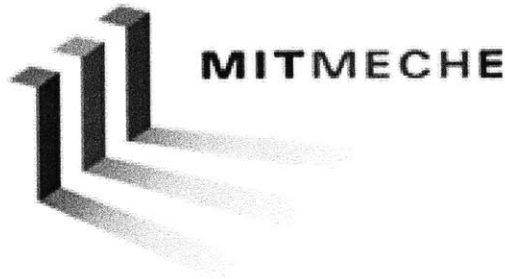


FIGURE 37: MIT Mechanical Engineering Logo

2. Translated into Vector images - All front etching is designated in black, full etching in red, and no etching in white. Back etching would be designated in blue and could not overlap with anything in black.

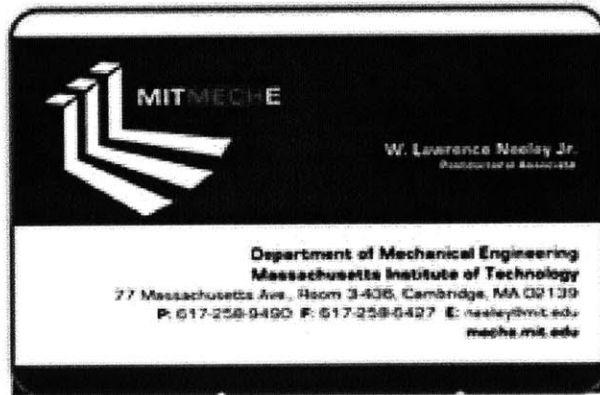
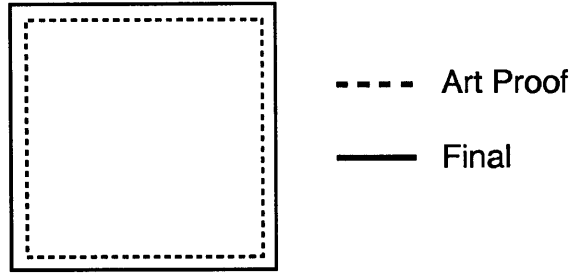


FIGURE 38: Vector artwork created to send to chemical etcher to obtain Figure 36

3. The final result in stainless steel in Figure 36

Due to isotropic etching, all etches will increase 0.006" at all points from the center of the desired mark. For example if you have a half etched box that is 0.1"x0.1", your resulting box will have the same center but have the dimensions of 0.112" x 0.112"



3D shapes can be made by adding snap fits and bending. Bending is a fairly simple addition and can add a lot to the product. You can either add an etched line or a line of etched wholes to make the bending line clear and weaken a specific area in order concentrate the forces to get a clean edge.

There are few more things to include when developing the artwork for chemical etching:w

- All artwork must be in the RGB colors:

Black R:0 B:0 G:0

White R:255 B:255 G:255

Red R:255 B:0 G:0

Blue R:0 B:255 G:0

- The final product must be surrounded by at 2 pt. Red line and then attached to the full sheet by two tabs. This can be seen on the card above with the surrounding red line and two white tabs at the bottom of the card.
- Potential metals included Stainless Steel and Brass. There are others but we have not explored them yet.
- The sheet size used by our manufacturer is 12"x20". There is a potential for other sizes but this is what is easiest and cheapest to get done quickly.
- There are several steps for the final translation for the manufacturer.
 1. Finalize placement of objects on the sheet
 2. Make sure everything is outline correctly and has tabs
 3. Save full file

4. Turn all red vector lines into black, and take all red fills and change them to black
5. Turn all blue vectors and fills into white
6. Make sure file then looks like a black representation of everything that you'll see on the front of the sheet.
7. Save as "front" file
8. Go back to original full file
9. Turn all black vectors and fills into white
10. Turn all blue and red vectors and fills into black
11. Make sure file is a black representation of everything to be etched on back
12. Save as "back" file

4.2 CHEMICAL ETCHING PROTOTYPING

Prototyping flatRat with chemical etching was another step up in cost and fidelity, so there wasn't as much iteration and a longer turn around time with each prototype. Each prototype needed to be carefully designed and all the potential issues worked about before outsourcing the files to be etched. The cost of prototyping was still smaller than most industry prototyping processes but they were much higher than both the laser and paper prototyping cost. Each prototyping run would be a 12"x18" sized sheet that we could prototype over which would have a 1 time tooling cost of \$100 and a subsequent \$80 per sheet etched with the same design. The large sheet allowed us to test a lot of prototypes per run, but there was also no learning factor that comes with quick iteration. I had to put a lot of different things on one sheet with the hope that 1 would work well. If something didn't turn out, we had to reiterate and test again that would be another couple hundred dollars.

This completely changed the process that we had been working with previously. There was a risk and cost involved with each prototype, leading me to be a little more cautious with how much we explored. The size of the sheet did allow us to try some interesting things, but the functional prototypes needed to be fully tested and refined in order to avoid redesigns and higher costs. This change in design brings up an interesting point of how cost associated with prototypes limits creativity. When there is a risk involved, ideas become more conservative to avoid large failures and losses. Even though it wasn't my money being spent, I was still conservative and didn't vary designs by extreme increments. I was able to

explore with the laser and paper without having to worry about any real cost being lost, but there was something on the line so I withheld from doing anything over the top. Looking back this naturally prohibitive mentality was terrible for what we were trying to accomplish. For the future, these pressures need to be alleviated and even though there is some cost, there needs to be the same level of exploration as the earlier stages. There are so many possibilities in this new medium and designs shouldn't be limited by cost savings.

The first set of prototypes to come from our manufacturer focused on one design of flatRat with a lot of small variations within the same design. The main prototype in Figure 39 includes the flatRat as 5 pieces to be snapped together. The pieces are attached to two cards: (1) a credit card sized card so you can keep flatRat in your pocket and (2) an exterior packaging card that has information, labels and pictures. These are all held in place by tabs that bridge the gaps that can then be broken by twisting the pieces out.

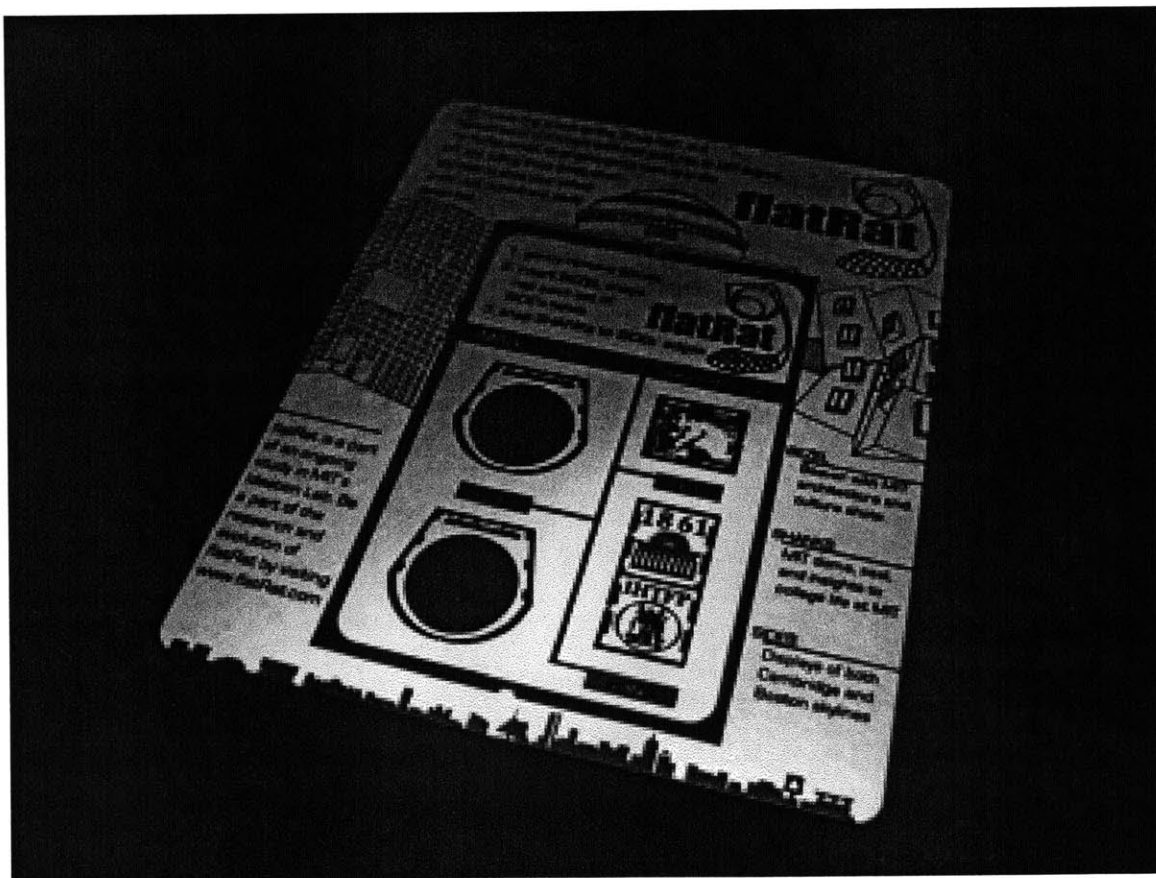


FIGURE 39: First brass chemically etched flatRat prototype with exterior metal “packaging”, interior wallet insert, and flatRat components.

This prototype was a first attempt at creating an aesthetic product that was compelling at a point of sale within a store. This included a new logo, adding graphic of the MIT campus, and refining the graphics on the ring itself. This process turned out to be fairly difficult. It required creating a dynamic product image and graphic layout that all played into how the user interacted with the product and why they would want to buy it. The first few iterations mocked up on the computer turned out confusing or convoluted, with a lack of focus on the product. By creating a defined graphic style, choosing a consistent typefaces and overall product look and feel, I came up with this first iteration. It had all the look and feel that we were going for along with all the information and excitement that we wanted to created around the product.



FIGURE 40: Optimized snap together flatRat based on multiple variations on each piece

The assembled prototype as seen in Figure 40 began to resemble the real look and feel of a Brass Rat. This prototype is completely snap fit together with similar interaction points as the last laser cut prototype. The iteration featured in Figure 40 is an assembly of the best fitting pieces of 10 different variations of each piece in order to find the optimal sizes for each snap fit.

With these interactions, the ring was actually fairly difficult to assemble because of its small size and thin metal pieces. Unlike the plastic pieces, they would torque out of place and would be very difficult to hold in place until the final pieces were put on. There was also a large variability from piece to piece. One side piece meant to have the exact same dimensions as another would be off by .005" which is enough that a snap fit won't work correctly.

There were also some problems with the overall product assembly and the multiple pieces. With so many small pieces held in place by tabs, they would easily catch and twist out of the card when you didn't want them to. This problem was addressed in the next generation but started bringing up larger issues of how we want to present the ring.

The next iteration looked to address the difficult assembly of a small ring and how I could reduce the dexterity required to put the ring together. Figure 41 shows the second flatRat prototype which reduces the part count of the ring to 2 pieces.

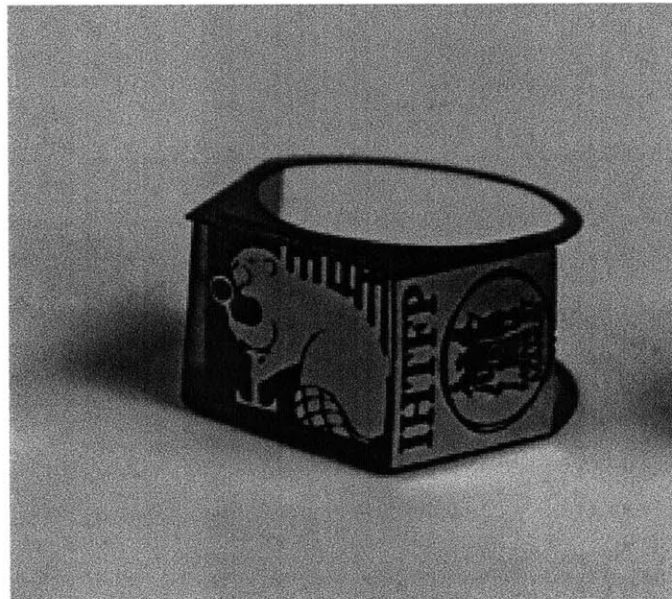


FIGURE 41: Folding and snap together flatRat in made from Brass with etched graphics.

All of the outside surfaces are one piece that is bent along the edges and the bezel is then snapped into the center of the ring. This prototype was much easier to use but there were still issues of getting consistent snap fits to work with the bezel. Some would fit and others wouldn't, which would be unacceptable in a final product. From the two prototyping

sheets we got in, it was more and more apparent that the snap fit that was successful in laser cutting would be difficult to master in chemical etching. Primarily from the tolerances of the manufacturing process but also the difference in thicknesses made it difficult to do correctly and in a way that was easy to assemble.

The next set of prototypes looked to improve on some of the issues of the previous two prototypes. One of the biggest concerns was what was going to happen with the large outside piece of metal once the ring had been removed. This was adding a large cost without adding anything functional or reusable other than a point of purchase display. The other issue, as mentioned, was the difficult assembling the small pieces by hand. The last was the long standing issue of how to address multiple sizes of rings. The current system requires multiple sizes of rings that fit a certain range of people, but as we developed the product this problem turned out to be a larger issue than expected and we had to refine our solution. These problems were resolved by the third iteration seen in Figure 42 below.



FIGURE 42: Brass and stainless steel prototypes with single folding flatRat

This prototype reduces the ring's part count down to 1 and all assembly of the ring is done by bending. This makes the user experience direct and easy to get from the 2D piece to the final ring, along with a much more robust look and feel. Once bent, it could easily stand dropping, wearing, playing, etc... without losing its form. Previous editions would fall apart with any kind of impact force but by taking out all of the weak interactions, the product became much stronger. With this change, I also redesigned the shape of the walls to more closely resemble the shape of the ring. This includes tapered sides and shanks, seen in Figure 43, similar to the taper of the Brass Rat. Previous iterations were more squared off and with the change the ring became less bulky and more in tune with the form of the Brass Rat.

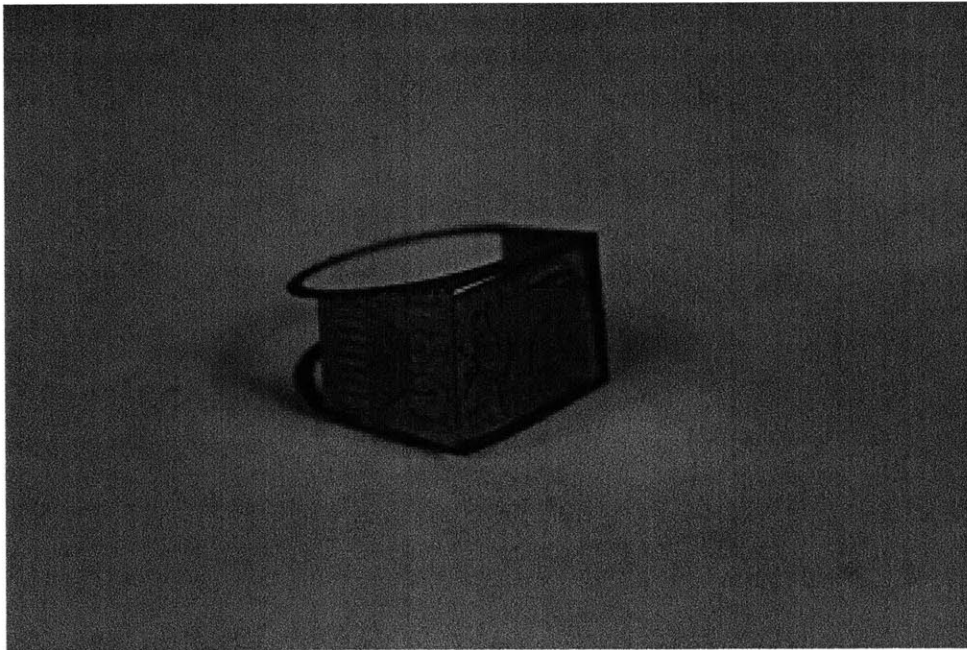


FIGURE 43: Stainless steel single part flatRat using only bending

The next major issue addressed by this prototype was how our product would be appealing to multiple sizes of fingers. Previously, we looked to make multiple sizes and people could buy the size right for them. This would give everyone a good fitting ring, but it created a huge problem from a business stand point. We would have to tool, store and sell all the sizes that we want to make, which adds more complexity and costs to the product.

Ultimately it was a lot of hassle for something that we didn't see as adding a lot of benefit. We decided to step back and define what the sizing of the ring meant to the user experience and how important it was to have one that fit just right.

We decided that having a ring that fits just right doesn't really matter. When someone purchases a flatRat, they most likely take it out of the case and fold it. They might try it on or play with it for a few minutes, but really won't wear the ring for day to day activities. By transitioning to metal we also started running into the issue of sharp edges. This would make a tight fitting ring potentially uncomfortable and unsafe if you jam your hand/finger while wearing it. With these conditions, we decided to go with a one size fits all ring that is too big for anyone to wear seriously but still have the shape and feel of a Brass Rat. By making it larger, we also made it much easier to use and put together along with giving more detail to the images on the ring as we increased the size. People will be able to put together the ring, play for a little bit, and then keep it as a memorabilia item. The different sizing only matters for the smallest part of the user experience and would potentially cause more problems than it would be helping.

The other major issue resolved was how to make the packaging component of the sheet could be used to not waste material like in previous prototypes. This prototype uses that extra material as a ring stand for the folded flatRat to sit on as seen in Figure 44. This addresses the need to store and show off the ring once it has been played with and doesn't just get thrown into a box or drawer. This gives it a specific place on the user's shelf to always enjoy the ring once its initial assembly is complete. This is done by folding the full piece in half and folding up a specially designed cantilevered tab that holds the ring in front of the dome and other campus graphics. This addition makes the packaging valuable to the user along with enhancing the overall user experience of the ring after they are done with assembling.

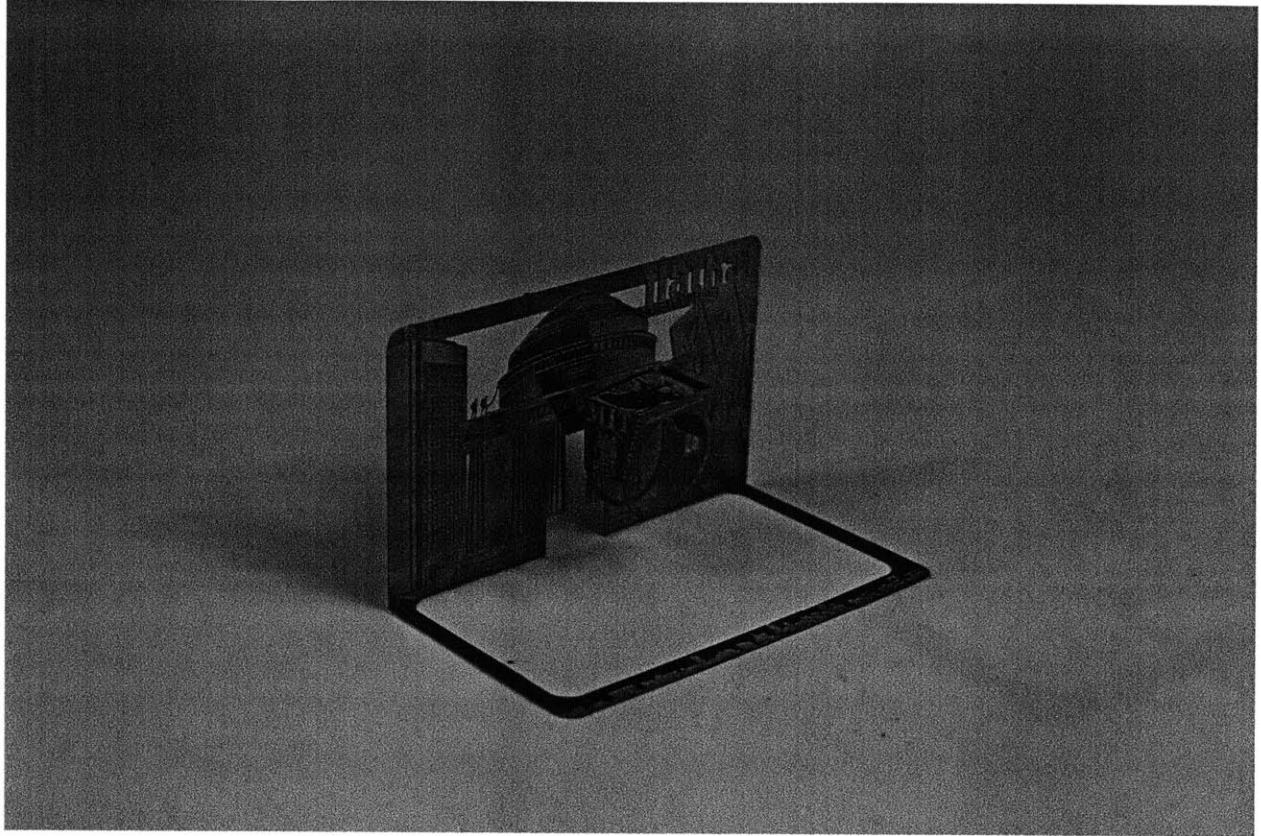


FIGURE 44: Single piece flatRat on folded stand

5 FINAL PRODUCT

This last prototype addressed most of the main issues that arose during the ring's development, along with evolving into product that we could bring to market. Most of the major components had been hashed out through each of the prototypes but there were still a few small issues that needed to be refined before we could take it to market.

During the last stages of our prototyping efforts in December of 2010, we began to shop the idea to several people that would potentially want to buy the product. The most important of those leads was the Brass Rat Ring Committee, the team responsible for designing the Class of 2013 Brass Rat. They were in the last few stages of their design process and we were able to get a meeting with them to present our idea. After the presentation, they decided to purchase our product as a give away during the upcoming Ring Premiere Ceremony. At this event, the Ring Committee debuts the design of the ring along with giving away prizes and gifts to the attendants, which this year would include a flatRat that depicted the design of the 2013 ring.

As we began negotiations on a contract, the most crucial factor became the cost per ring. With our current manufacturing costs we would have to charge them 16-20 dollars per flatRat, which was out of their budget for the quantities they were looking to order. In order to get the Ring Committee on board, I went back to the design in order to cut as much cost as possible and still deliver a quality product.

The easiest way to cut cost with chemical etching is to optimize the surface area that your product occupies. There is a direct and linear relationship between how many pieces you can fit on a sheet and how much they cost per unit. If we could reduce size and get more parts on a sheet, we could potentially save a lot of money.

After iterating through paper and computer mockups, I resolved to the prototype featured in Figure 45 below.

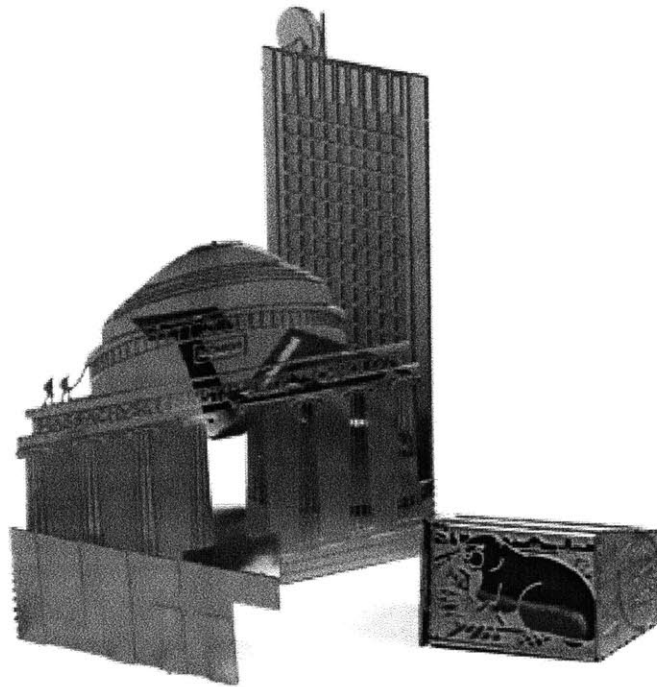


FIGURE 45: Separate ring and stand optimized for manufacturing and aesthetics

This prototype took a step away from the all in one packaging that we had been prototyping and separated the two components, the stand and the ring, into two different pieces. This paired with moving to a new manufacturer allowed us to take our total cost from \$10.00 dollars down to \$4.87 for the two parts. This change made all the difference in our business plan and allowed us to put together a full product for a reasonable price for the Ring Committee.

The new prototype not only optimized our cost structure, but it was also a better product with more appealing aesthetic. There was no unneeded area for logos or instructions but each piece only had what it needed. It also removed the need to twist out the parts from a larger piece which would often leave a sharp bur or potentially damage the part. This strategy requires a dedicated package but we were able to source those for under 10 cents a piece compared to the extra 5 dollars that having the metal packaging which would need a protective cover anyway. This way we could focus on the aesthetic and functionality of the ring and separate the instructions, logos, and graphics into card stock card.

The ring is the exact same as before except that our final product is only produced in brass as seen in Figure 46. The stand has the same dome component with cantilever ring stand but added are the green building and MIT logo that fold in front and behind the great dome in order to balance the product.

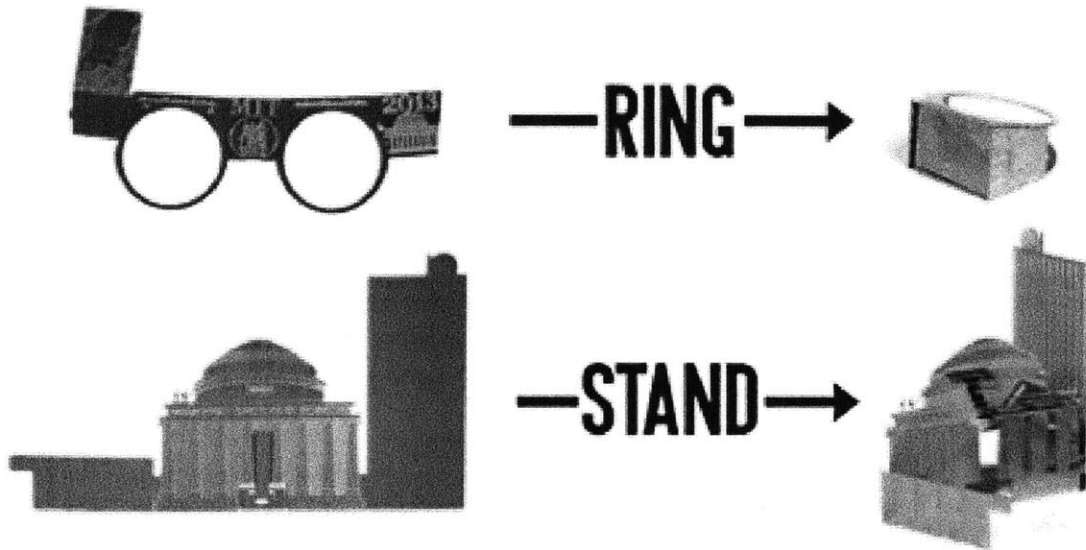


FIGURE 46: Individual components, the ring and the stand, fold to give 3D parts

The stand was also optimized to not only hold the flatRat well but can also be a stand for the actual Brass Rat as seen below. This added functionality allows the consumer to use it in multiple ways and give it a higher perceived value for its novelty.

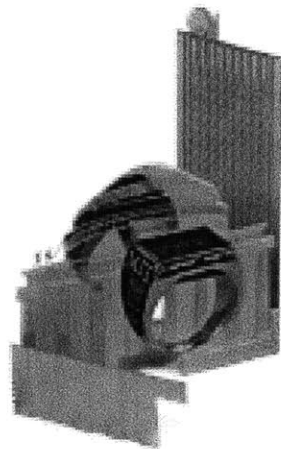


FIGURE 47: flatRat stand holding 2011 Brass Rat

With the two separate pieces, we needed to source packaging that held the stand and ring together and could be distributed. The easiest and cheapest way to package the product was with a cellophane bag with card stock insert with instructions. The card stock insert would give the package some structure to protect the brass pieces from inadvertent bending during shipping and handling. The card stock also served as a divider between the two brass pieces in order to protect them from scratching one another.



FIGURE 48: Final packaging design for manufacturing run for Class of 2013 edition

It also allowed us to add more graphical instructions, logos, and history shown in Figure 49, that couldn't have been added otherwise. The company that printed the inserts also had the capability to double side print and crease for folding which allowed us to fold the card in half and add all the instructions to the inside the packaging.

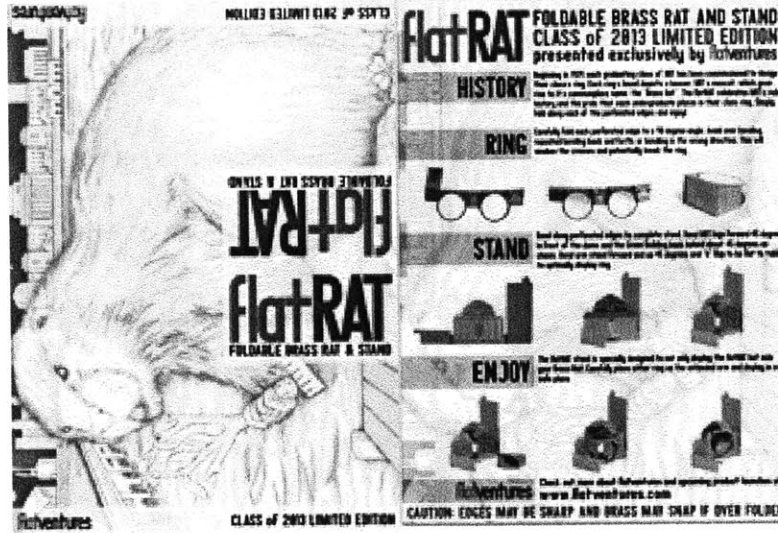


FIGURE 50: Exterior of card stock insert (left) and interior graphics and instructions (right)

With the product complete and all components set, we were able to go ahead with a full manufacturing run. Our first run produced 420 flatRats and sold at a price of \$11.00 a piece to the Ring Committee to give out to the first attendants at Ring Premiere. The Ring Committee debuted the design for this years Brass Rat followed by the world premiere of the flatRat:Class of 2013 Limited Edition as shown in Figure 51.

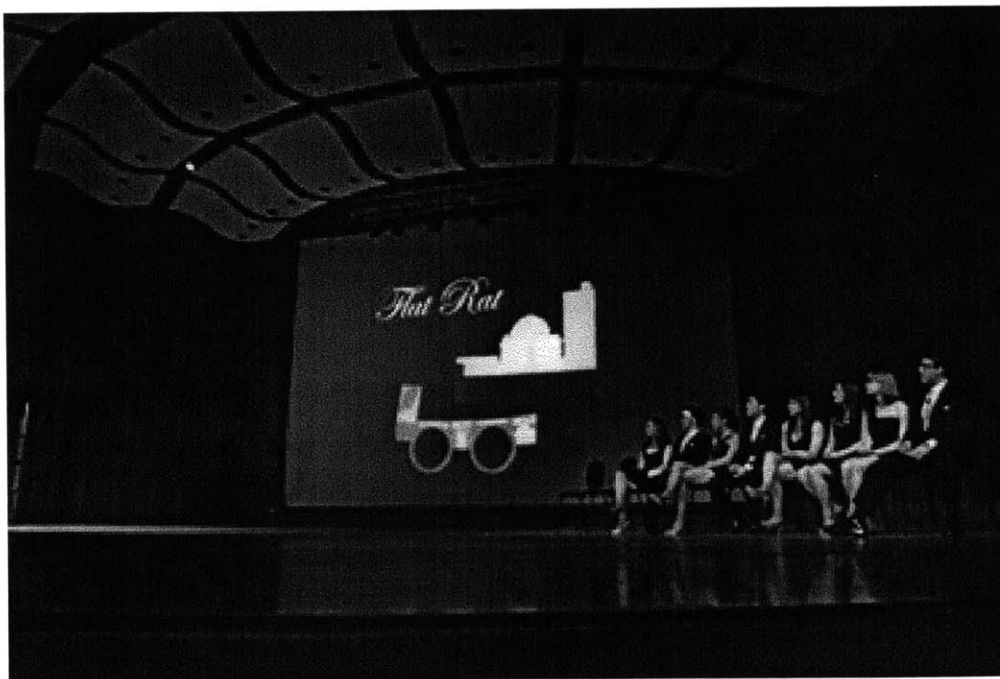


FIGURE 50: flatRat debut at 2013 Ring Premiere Ceremony on February 11, 2011

DISCUSSION

Over the past two years, our team has worked to develop not only the concept of flatRat but also the motivations and structure behind it. This project was a definite success, bringing a concept from the early stages of ideation to a final product sold to consumers. It was also successful in how we created it, accomplishing everything with a small budget, accessible tools and limited man power. This builds into the overall goal of passing this process onto others in a similar position, with the hopes that they can bring another product to life.

This goal is already being realized with the work of Dr. Lawrence Neeley at Olin of College of Engineering. Engineering students with little product design experience are beginning projects with this process and turning them into flourishing businesses from Dr. Neeley's classes. With all of the knowledge and tools we've put together over the past two years, Dr. Neeley has been able to optimize the process to the point where his students go from concept generation to final product in about 6 weeks. This is a tremendous success for the next levels of this project, spreading product design and making the once daunting process accessible to a greater population. There is no doubt that this project will continue to grow and thrive at Olin, and hopefully spread past the college classroom to the real world, bringing more products to life.

The most interesting part of this project was how much I gained outside of my core Mechanical Engineering curriculum. Many of the things I learned through this project I would have never experienced in a standard education and in my opinion, these experiences have the most potential to contribute to my career. This is most evident in the non-technical aspects of the project, in particular the communication and organizational skills required to get a concept off the ground, through manufacturing and onto store shelves. Engineering often gives you the tools to design something well, but leaves out some the crucial aspects of bringing it to life in the real world.

There are big steps to between a proof of concept to a full product reliant on cost, user experience and clients needs. Some classes try to address these issues but most of the time the issues are diluted to the point that you don't actually deal with real world issues.

The difference between talking about “Design for Manufacturing” in a class compared to actually talking to a manufacturer about design issues is a huge. By having a real conversation with a real manufacturer you learn some of the basic skills and tools need to get something made on a large scale. I imagine these would be learned in the first few years working in industry, but by learning them during my time I college, I changed how I focused in my education and how the technical skills I learned in class actually apply to business related situations.

There is also very little focus on how certain design decision change the entire business structure of a product. With most project based classes, you spend the entire semester getting a product to work. You choose the most efficient way to do something, use the optimal materials, and spend whatever it takes (or up to the allocated budget) to get it to look nice and work well. The difference in this project was that we were always designing a product to sell. There was no deadline for getting it done, no grade with how well I implemented a design prompt, and plenty of constraints that come with a real world project. These real constraints influenced the entire scope and focus of the project, making it feel a lot less tangible at the beginning but a far greater accomplishment by the end.

There is something to be said about how this project influenced my education and how much it contributed to how I learn and grow as an engineer and designer. By seeing something evolve from a vague concept to a product in the hands of 500 students around campus is far more satisfying than my other engineering projects. flatRat was one of the least technical projects I worked on while at MIT, but it was also one of the most challenge in its depth into the process. It required me to stretch far beyond my engineering training and into the realm of design theory, business strategy, and team communication. By adding all of these factors, it changed how I thought about the process and changed how the product ended up coming to life. Every one of these stages of product design influence one another. If one part of the business strategy changes, the design of the product should change with it. Engineering students often only see the one side and they design without a reason or influence from these other factors, often leading to products that can't get off the ground. With a constant balance and investment into each one of these branches, a product can fully come to life and thrive.

I would recommend that all engineering students aspiring to go into product design engage in similar project at some point in their education. There is incredible value in creating something that you want to bring to market. Project based classes have value in experiencing some of the basics of the design process, but there always something missing. There is a focus and drive that comes from a product that is meant to be real and it's success rides on how the consumer reacts to it, not how a professor or reviewer deems it worthy. This is the ultimate test that designers in industry go up against every day and there is no protective layer like what occurs in academia, along with no limits to the success of the product.

Seeing a bit of the real world before graduating has given me a taste for what it takes to thrive in it and has encouraged me to explore more in it. I will always want to keep making new things, present them to the world, and see how the world reacts. This project was my first real experience with design, business and product engineering, and I will always be grateful for it's influence in finding my passion in product design.

If you'd like to discuss this project further, have any particular questions, or any other inquiries, please feel free to email me at gwinther13@gmail.com.

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- [1] http://www.pmiphil.com/images/sample_materials/big/Elephant_Puzzle.jpg
- [2] http://acreativeedge.info/pic01/BK-KN-SN908_Multi_Tool_01.jpg
- [3] <http://weburbanist.com/2009/03/22/15-of-the-worlds-most-brilliant-business-card-designs/>
- [4] <http://www.bottleopener.com/images/P/6050%20Pro-Cap%20Opener.jpg>
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- [6] Osborne, Alex. "Applied Imagination: Principles and Procedures of Creative Problem Solving." New York, NY: Charles Scribner's Sons, 1953, Paperback.

APPENDIX A

Basic Description	Link	Comment	Comment
	http://www.foldschool.com/	did you check out foldschool yet? cardboard tutorials for furniture - justin	http://delicious.com/jlai321/2.97
	http://www.tamasoft.co.jp/pepakura-en/	also pepakura designer and the papercraft hobby - justin	http://delicious.com/jlai321/papercraft
Foldable Dice	http://www.chungdha.com/2007/11/fold-able-dice.html		
Toy Figures	http://boards.cora77.com/viewtopic.php?t=15791		
All Things Business Cards	http://boards.cora77.com/viewtopic.php?t=18392&postdays=0&postorder=asc&start=0		
Ice Scraper/Window cleaner	http://www.cnpromotiongifts.com/UploadFile/ice-scraper-kt2004-1403.jpg	My mom uses this a lot, seems like a lot could be added to it	I can't see this link. Is it to an email message? -law
ipod/phone holder	http://www.swiss-miss.com/2009/03/crabble-versatile-iphone-stand-for-your-wallet.html		
mini scissors	http://www.swiss-miss.com/2009/03/snip-snip.html		
be sure to check out touch of ginger -lawrence	http://www.touchofginger.com/product/browse/27		
Puzzles -maria			
stickers -maria			
Dinosaur skeleton -maria	http://www.amazon.com/T-Rex-Skeleton-Dinosaur-Assembly-Set/dp/B001L9FLSA		
Target giftcards	http://www.target.com/GiftCards/b?ie=UTF8&node=14061591	These physical giftcards are very imaginative - one becomes a balloon, another becomes a USB drive, one becomes a reusable tote bag	
Credit card multi tool	http://www.kk.org/cooltools/archives/001782.php		
watch	http://www.selections-web.co.uk/hardware/images/TU01-Torch-Watch-flat.jpg		
stars flat -> chair	http://s3files.cora77.com/blog/images/formium.jpg		
ipod earbud storage	http://gadgets.kenxu.com/assets/uploads/2008/12/multicolor-earbud-clips.jpg		
"	http://craziestgadgets.com/wp-content/uploads/2009/05/owl-earbud-holder.jpg		
pencil holders	http://www.crobike.de/en/werbemittel_bilder/promopeddler/14400/26506.jpg	can be made with more durable material	
toy "paper" airplanes			
erector sets	http://sunboar.files.wordpress.com/2008/06/erector-set.jpg		
simple legos	http://l.ihow.com/images/GlobalPhoto/Articles/4914190/166677-main_Full.jpg		
sleak desktop legos	http://www.theimaginaryzebra.com/images/blog/052109_12.JPG	killian+dome, green building, stata center	http://shop.lego.com/Product/?p=21002&cmp=afc-cs&na&hqs=21002
3d puzzle	http://img.diytrade.com/cding/393462/2890001/0/1162276329/3D_puzzle_Plane_wooden_toy.jpg		
3D printing style puzzles	http://www.puzzlehistory.com/3dmtrsm.jpg	do mit architecture this way	
origami rings	http://kazufujiatuo.id.infoseek.co.jp/origami2005-06-05_000.jpg		
"how to" origami ring	http://images.google.com/imgres?imgurl=http://www.origami-instructions.com/images/dollar-ring/thumbnails/14-money-origami-ring.jpg&imgrefurl=http://www.origami-instructions.com/money-origami-ring.html&usq=__u4JulaXpo0QI5Cgdk-gNyOKT32g&h=370&w=400&sz=37&hl=en&start=6&sig2=0GLFa-fInnBQc1QbnTntA&um=1&tbnid=c2sSZEgr-NfQ8M:&tbnh=115&tbnw=124&prev=/images%3Fq%3Dorigami%2Bring%26h%3Den%26client%3Dfirefox-a%26rls%3Dorg.mozilla.en-US:official%26sa%3DG%26um%3D1&ei=4vgnSrXWLHq wPTkBW		
flat top simple ring	http://ny-image3.etsy.com/i_fullxfull.57882907.jpg		
emergency cufflinks -> flatrat	http://www.touchofginger.com/product/view/emergency-cufflinks	durability of hinges?	
foldable fork	http://www.homesupplies-b2b.com/b2b/pics/Plastic_Folding_Fork.jpg		
all in one sporkknife	http://ecx.images-amazon.com/images/I/216yKv1mdSL_SL500_AA280.jpg		
music related			
drum key	http://www.drumshack.co.uk/uploads/images_products/747.jpg		
guitar string winder	http://e-media.leeward.hawaii.edu/frary/string_changes_images/String_winder.jpg		
guitar string cutter	basically a wire cutter		
guitar capo	http://www.russiavalley.com/KeyserGuitarCapo.jpg	it would be really nice to have all of these as one tool	
modular furniture for desktop organization	http://img.en.china.cn/0/0,0,84,17076,1100,731,61110c92.jpg	basic flat/easy components, and then build to need	"adult legos" made to have finalized purpose and still have personalization and construction factor
cool all in one wallet tool	http://www.pogadget.net/images/CC15B.jpg		
foldable stuff		go from non flat to flat	
drying rack	http://www.chinatradersonline.com/Files/Household/Clothes-Hanger/Foldable-Drying-Rack-23404631868.jpg		
chair	http://www.chinawholesalegift.com/pic/Family-Product/Chair/Camping-Foldable-Chair/Wales-Flag-Foldable-camping-chair-21175256646.jpg		
leg rest	http://www.alphamarque.com/health/images/Foldable%20Leg%20Rest.jpg		
art -> chair	http://www.furniturestoreblog.com/images/FOLDING%20CHAIRS.jpg		
homemade laser cut product	http://www.instructables.com/id/Open_Manufacturing_How_to_Build_30_SERB_Kits/#		
boxes from flat beginning	http://fab.cba.mit.edu/classes/MIT/863.08/people/scott/3dobj.jpg		

APPENDIX B

LASER CUTTER HOW TO:

Solid Works Program Files on Separate Computer

1. Move parts to one SolidWorks draw file
 - a. Set size of draw file to be 24" Wide x 12" Height
 - b. Insert all desired pieces into draw file
 - c. Make sure all parts are set to a 1:1 ratio
- NOTE: Laser cutting is only 2D. Any three dimensional variation will not be included.
2. Save file as .dxf
 3. Load to mobile storage device

From other vector programs (Illustrator...)

1. Create all cuts in one color (either red or black) and all the raster images in the other color (the opposite of the cuts).
2. Create a "Group" of all the cuts together and another of all the images
3. Export as either .ai or .dxf

At the Laser Cutter

4. TURN ON Laser Cutter, Air Pump on floor, and computer
5. Login to account "Laser Cutter" with password: 20591
6. From mobile storage device open .dxf or .ai file with CorelDraw

Open CorelDraw on Windows

7. Set "Sheet Size" in top left corner to 24"x12" or the Legend Engraver sheet size
8. All parts from SolidWorks should appear as they did in the SolidWorks Draw file
9. Select all cut lines or grouped cut lines and set thickness of line to "Hairline" for anything that you wish to vector cut (cutting all the way through). Make sure only lines you want to cut are show on the page

note: thickness setting looks like top of fountain pen

10. If you want to raster cut (engraving), all lines that are not Hairline thickness will be rastered. It is easiest to add these after you have your vector lines set to hairline and you don't want to make any more changes to what will be vectored

PRINTING

11. Hit Print and select the Legend Engraver as the printer
12. Go to printer properties/settings
 - a. For vector cutting .06-.15" acrylic settings should be
Speed:10 Power:100 Frequency:5000
 - b. For raster cutting acrylic, depth is relative to speed
Deeper Cuts Speed:10 Power 100 Frequency5000
Surface Engraving Speed:50 Power 100 Frequency:5000
Lower Speed to increase depth of cut. Lowering the speed too much may cause melting of the plastic. This occurs around Speed=10

13. Hit Print

CUTTING

14. Double Check air pump is on and there is adequate ventilation(make sure vent gates are open on ducts)

15. Place plastic in bed

16. All pieces as they appear on the 24"x12" board will be cut accordingly on the plastic relative to the top right corner of the bed.

16. Go to "Jobs", and select job you just sent

Double check that everything looks as you want it

17. Hit run

-Do not try to open bed before job is done

-If you want to stop hit the stop button twice to cancel job

**Always watch progress of machine to make sure it is only making one cut and the cuts you want

***Acrylic and other materials are flammable so monitor for flames and immediately cancel and double check that the vent and pump are working

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