Mechanical Engineering 310
Spring Design Proposal
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1 Front Matter

1.1 Executive Summary

Background

The growing demand for electronics and computers has reached a fevered pitch in recent years. As technology continues to play a larger role in our lives, the issue of electronics waste must be addressed. The EPA estimates that 1.3 million tons of computer products (desktops, laptops, monitors) alone were ready for end-of-life (EOL) processing in the U.S. in 2007.[1] Spurred by the environmental need, governments across the globe are increasingly regulating how products must be dealt with at the end of the product life cycle. Recent EU directives such as the WEEE (Waste Electrical and Electronic Equipment) and RoHS (Restriction of Hazardous Substance Directive) address laws that mandate collection, treatment, recycling, and recovery of electronic waste at the product end-of-life.

Autodesk challenged this team of Stanford and Aalto students to find a novel solution to this problem by developing a fully recyclable electronic product. What if a new wave of electronic products became available to the consumer that drastically simplified the recycling process? What if these new products were not only green, but they were slim, sleek, and sexy? What if recycling became so simple for the consumer that they could do it without ever leaving their home?

Current Progress

Nine months of research, needfinding, prototyping, and user testing left the design team with a number of significant insights into the world of consumer electronics recycling, or "e-cycling." The first key insights were gathered as the team sought to better understand the problem space of e-cycling. The team discovered that recycling problems go beyond e-waste piling up in landfills and, in fact, stretch all the way into the realm of the consumers' interactions with their electronic products. Lack of consumer awareness, the inaccessibility of recycling locations, and the inconvenience of the recycling process are a few of the reasons why landfills all over the globe are piling up with electronic waste. With all of these unfulfilled needs and issues, it is clear that the end-of-life experience for consumers is, to tell the truth, incomplete. This is the area that the Autodesk team chose to focus on for the project: redefining the relationship between consumers and their electronics.

As such, the Autodesk team's goal for this project was to develop a recyclable product solution that makes recycling a more effective, engaging, and complete process for consumers, and thus decreases the amount of e-waste that gets added to landfills each year.

The Autodesk team's goal and vision have been realized in the form of the Bloom laptop. Bloom represents a new class of electronic products that is more recyclable than other laptops, but also offers an improved experience.

[1] http://www.epa.gov/waste/conserve/materials/ecycling/docs/app-1.pdf

More recyclable

Bloom can be easily disassembled and separated into material types (plastics, metals, and circuitry) so that each can be reused or recycled to the fullest at EOL. In fact, Bloom is so easy to disassemble that consumers can do it from the comfort of their own home! What makes it so easy?

Bloom can be disassembled in 10 steps and without tools. Compare this to a MacBook, which took a team of three engineers 45 minutes, three tools, and 121 steps to disassemble.

In order to facilitate the disassembly process, graphical instructions are integrated into the laptop's design so that each step in the disassembly process is crystal clear.

Smart material choices. The Bloom casing is completely made out of aluminum and can be tossed directly into a home recycling bin.

Over the course of the project, the team learned that recyclability is not a strong enough selling point (by itself) for consumers, especially when it comes to high-tech electronics. As such, the team found it imperative to utilize elements of design for disassembly to make Bloom become functionally differentiated from competitors.

The team came to call this the "Green as a By-Product" approach. The benefits of Bloom not only enhance the user experience, but also make room for a new kind of business model. In this model, hardware turns into a service, so that buying a computer is no longer a one-time investment, but instead becomes a lasting relationship between the consumer and the service provider. The following two features (easy reparability/upgradability and the modular keyboard) of Bloom are derived from this green as a by-product approach.

Enhanced User Experience

Because Bloom is incredibly quick and easy to disassemble, repair or upgrade of internal components becomes a snap. Not only does this take a lot of the cost and hassle out of electronics repair, it also increases the overall lifetime of the product.

Another functional benefit the team established with Bloom is a wireless modular keyboard. The team observed people using their laptops in public spaces and quickly noticed that the key problem with laptops is ergonomics. With a detachable wireless keyboard, the keyboard and track pad can be removed from the laptop, allowing for a wider (and more comfortable) variety of use scenarios.

The Autodesk team believes that involving consumers in the larger life cycle of their products will change the way people think about electronics, and recycling will increase significantly. Bloom is the first product manifestation of this concept; hopefully, Bloom and the ideas behind it will lead to a future of entirely new and recyclable electronic products.

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1.5 Glossary

1.5.1 Terms

Active disassembly	Fixings that are made from smart materials that are designed into a product to aid disassembly, for e.g. fixings that can be activated by a particular process or stimulant at the end of life stage.
Brainstorm	A tool used in idea generation, either through generating as many ideas as possible in a set time frame, or by prototyping ideas to answer questions.
Dark Horse	A usually little known contender that makes an unexpected good showing.
Down-cycling	The recycling of a material into a material of lesser quality.
EPEAT	EPEAT is a system that helps purchasers evaluate, compare, and select electronic products based on their environmental attributes.
E-waste	Discarded, broken, obsolete, or surplus electronic devices.
EXPE	Stanford University's annual spring mechanical engineering design exposition, where all projects from graduate engineering classes are displayed.
Functional Modularity	A part or a component of the product can perform different functions or can be used in a multiple ways.
Greenwashing	The practice of companies disingenuously spinning their products and policies as environmentally friendly.
Internal Motivation	Motivation that stems from personal believes or values. For example, the desire to dispose of waste properly in order to preserve the environment.
Hatch	The locker inside Bloom laptop where PCBs are attached, secured with doors and latches.
Joint	A place where two things or parts are joined.
LaserCAMM	A machine that uses a small laser to cut or etch shapes out of a variety of materials, including plastic, paper, wood, and sheet metal.
Motherboard	The primary circuit board of a computer, usually containing the microprocessor as well as other peripheral components. In a laptop, the motherboard is usually heavily integrated.
Needfinding	A research method used to uncover user needs.
Pyrometallurgy	As the name suggests, pyrometallurgy involves the combustion of the recyclable products to form molten alloys

Pain point	A problem or level of difficulty sufficient to motivate someone to seek a solution or an alternative.
Resin identification codes	The SPI resin identification coding system is a set of symbols placed on plastics to identify the polymer type: for example PET, PS, and PP
Seedbox	A biodegradable portion of the laptop that contains seed(s) within it and can be planted at EOL.
Single-stream recycling	A system in which all components are mixed together in a collection truck, instead of being sorted into separate commodities (newspaper, cardboard, plastic, glass, etc.)
Up-cycling	The process of converting waste materials or useless products into new materials or products of equal or better quality.

1.5.2 Abbreviations

CAD	**Computer Aided Design** A method of designing components and structures using a computer as the drafting medium
CFP	**Critical Function Prototype.** A prototype that explores only one component or function that is considered critical to the project solution.
CPU	Central processing unit
DfD	**Design for Disassembly** Design concept that involves designing products with maintenance and remanufacturing practices in mind. One of the important issues in DFD guidelines is related to the selection of the connectors used in the product.
EOL	**End of Life** A term used to describe the state of a retail product when it is at the end of its functional product lifetime.
GUI	**Graphical User Interface**
LCA	**Life Cycle Analysis** The investigation and evaluation of the environmental impacts of a given product or service.
NCR	**Non-conventionally recyclable** Components which require specialized disposal and recycling methods, e.g. circuit boards, wiring, rubber, etc.
PCB	A **printed circuit board** is used to mechanically support and electrically connect electronic

	components using conductive pathways, tracks, or traces, etched from copper sheets laminated onto a non-conductive substrate.
POV	**Point of View**
PRL	**Product Realization Lab** is a lab at Stanford University that provides students with access to manufacturing tools such as lathes, mills, welding sets, laserCAMMs, etc.
SLA	**Stereolithography** is a rapid prototyping method that involves depositing small amounts of materials into layers to create a three-dimensional structure. Also known as 3D printing.
SGM	**Small Group Meeting** A meeting between the design team, the teaching team, and the team's coach.

2 Context

2.1 Need Statement

The printer you bought last Christmas jammed for the tenth time today, your laptop takes ten minutes to start-up, and that tiny TV in the living room is just too small. So you're on your way to the mall to purchase a whole new round of the latest technologies. But what about your old electronics? Well, that printer, TV, and laptop will just have to join that ever-growing pile of old electronics in the far corner of your two-car garage. In a few years these "new" devices will find themselves in the corner as well.

Figure 1 *Piled-up electronics*

As you are driving to the mall, your concern for the well-being of the environment grows. You know that electronics can't be thrown in the trash, that's why they pile up in the garage. You consider yourself to be environmentally conscious but simply don't know how to deal with old electronics. You could take them to the recycling center but that's 30 minutes away – and frankly it's just easier to ignore the problem.

But what if there was an easy way to deal with them? What if you could somehow end the unsustainable pile-up of e-waste without much effort? What if from the comfort of your own home you could recycle your electronic devices?

Sadly most of the new electronic gizmos are loaded with toxins, have short life spans and are not designed for recycling. The problem with electronics recycling extends beyond landfills – it stretches into the realm of the consumers' interactions with their electronic products, because the end-of-life experience for consumers is, to tell the truth, incomplete.

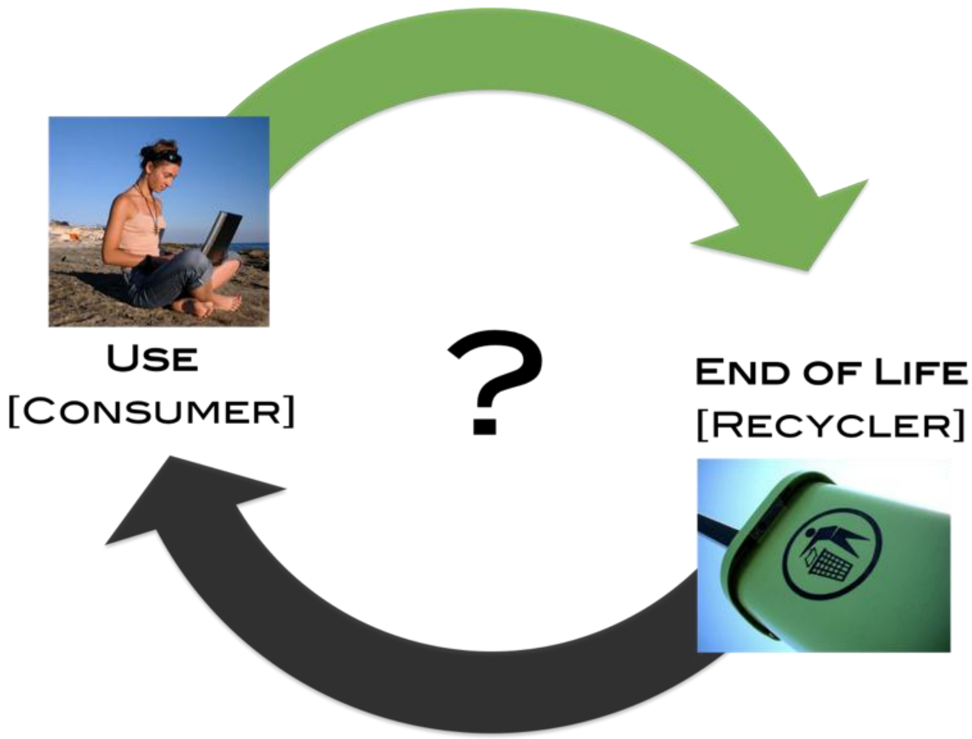

Figure 2 *There is a gap between consumer and recycler*

2.2 Problem Statement

The challenge for the team is to design and develop a prototype of a fully-recyclable consumer electronics product that can be disassembled easily and safely by the consumer at end-of-life while leveraging as much as possible the primary recycling methods available to consumers today. The product should also be modular in that its individual components can be easily removed, replaced, or reused. By providing a supporting business model that makes the product a service, the team aim to address the issue of user motivation.

2.3 The Design Team

Mechanical Engineering 310 (ME310) is a graduate-level course exploring the Stanford Design Process. Over the course of one academic year, students from around the world work in close collaboration to develop and implement innovative solutions to real-world design challenges. The Design Team is comprised of a diverse selection of students from US and Finland, from Stanford University, Aalto University, Lahti Polytechnic and Turku School of Economics. The Autodesk design team's final prototype was featured at Stanford's EXPE Design Experience in June 2010.

Stanford Team

Rohan Bhobe
Status: M.E. Graduate Student
Contact: rbhobe@stanford.edu

I'm a born-and-raised Chicagoan who can always spare a moment to argue that Michael Jordan's Bulls were the best basketball team of all time. I came to Stanford for my undergrad, where I completed my Electrical Engineering degree with a concentration in sensors/circuits and a minor in Computer Science. I am currently pursing a Masters degree in EE as well, and my coursework places emphasis on bringing EE, ME, Design, and CS together in a harmonious way. Outside of academics my hobbies include traveling, basketball, soccer, cricket, electronic art, hiking, rock climbing and scuba diving.

Skills: Circuit design, soldering, breadboarding, basic machining C++, C, Java, PHP, SQL, Visual Basic, HTML, MATLAB, Verilog, Virtuoso

Aaron Engel-Hall
Status: M.E. Graduate Student
Contact: aaroneh@stanford.edu

Born in the best city on earth (Chicago of course) I lived on the south side for 18 years before I came out to California for my undergrad years at Stanford. I studied Physics as an undergraduate and decided to continue on at Stanford to pursue a masters in M.E. in order to get experience with what I love most - actually designing and building things instead of discussing them theoretically. Outside of academics my hobbies include soccer, basketball (although I'm awful), listening to music, playing drums, hiking, traveling, and animated comedy shows (think simpsons, south park, futurama...).

Skills: Machining, circuits, soldering, AFM, mass spectrometry, high frequency lasers, MATLAB, Mathematica, COMSOL Multiphysics

Kirstin Gail
Status: M.E. Graduate Student
Contact: kmgail@stanford.edu

I was born in Los Angeles and raised in Boulder, Colorado. I received a BS in Engineering (Product Design) with a math minor from Stanford last June and am now in the co-terminal (Masters) program in Mechanical Engineering. I love surfing, scuba diving, swimming, and playing in the ocean waves.

Skills: CAD, basic machining, Illustrator, Photoshop, fluent in German

Helsinki Team

Juho Huotari
Status: Industrial design student
Contact: juhohuotari@gmail.com

I was born in northern part of Finland in a small city called Oulu. That is probably the second best city above earth. I was raised in an even smaller fisher village in Haukipudas called Kiviniemi. I was studying ME in Oulu University for one and half year until I "found" my real interest, industrial design. I´m really eager and fast to learn new things, I enjoy finding new methods and ways to solve problems. I enjoy to work in group as it is much more efficient to develope new product in team. Top quality of designing the product from beginning to very end is my point.

Designing the shape of the product itself is interesting but the most interesting is to find the way to get the product function and to be easily used. I am interested to explore different materials and the ways they can be used. I own good technical skills. I have a lot of experience in model building. I am able to easily solve technical problems and create efficiently new ways to handle the case to find the sensible result. Outside of school my hobbies include pushbiking, snowboarding, jogging, listening to music.
Skills: Model building, Rhinoceros, Adobe -photoshop, -Illustrator, -Indesign.

Markku Koskela
Status: M.E. GraduateStudent
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Born and raised in Helsinki, Finland. Studying mechanical engineering in Aalto University (formerly Helsinki University of Technology). I'm very interested in designing, prototyping and the product development process as a whole. Last year I was a part of a team that designed a new concept of a building maintenance unit as a school project.
Other interests include sports, especially snowboarding, and getting familiar with different cultures trough traveling.
Skills: CAD-modeling (Pro/Engineer, SolidWorks and some Catia). I also have basic machine shop experience.

Linda Liukas
Status: Business Graduate Student
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I'm a fifth year marketing student from Turku School of Economics with a motley collection of studies in communications, entrepreneurship and visual journalism. So far all my experience from multi-disciplinary work has been from business development side, ME310 is my first actual product development course. My interests include web, mobility, startups and watching soccer.

Chongbei Song
Status: I.D. Graduate Student
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I'm from China, now studying at University of Art and Design Helsinki, major in Industrial and Strategic Design, minor in International Design Business Management. I'm Interested in multi-disciplinary and cross-cultural co-operation, specialized in user-centered design, design strategy, innovative design approaches, design management, interactive prototyping and 3-D modeling. My hobbies include photographing, travelling, shopping, swimming, and watching movie.

Skills: Rhinoceros, V-ray, Pro/Engineer, Photoshop, Flash, some Visual Basic and Arduino.

Stanford University, USA

Stanford is recognized as one of the world's leading universities. Its renowned faculty offers students a remarkable range of academic pursuits that are paired with an extraordinary breadth of extracurricular activities and opportunities for research and public service.

Aalto University, Finland
Aalto University is a Finnish university established in January 1, 2010. Aalto University aims to create a new science and arts community by bringing together three existing universities of technology, economics and art. The new university's goal is to be one of the leading institutions in the world in terms of research and education in its own specialised disciplines.

Lahti University of Applied Sciences, Institute of Design, Finland
Institute of Design is a part of Lahti University of Applied Sciences, which is a large, multidisciplinary institution of higher education. Their aim is to educate professionals to work in society and business with the ability to design and give concrete and visually perceivable form to objects, communication and services in our society.

Turku School of Economics, Finland
Turku School of Economics is a faculty of the University of Turku. It was the second largest business school of its kind in Finland, with approximately 2,000 graduate students. In January 2010, Turku School of Economics became the seventh faculty of the University of Turku.

Coaches

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2.4 Autodesk

2.4.1 Company Background

Autodesk, Inc. is a world leader in 2D and 3D design, engineering, and entertainment software, Autodesk helps customers address these challenges by providing the tools to help seize opportunities created by a new global business environment.

2.4.2 Contacts

Primary Liaison Peter Vinh Autodesk – Lake Oswego, OR peter.vinh@autodesk.com	**VP Worldwide Learning & Education** Joe Astroth Autodesk - San Rafael, CA joe.astroth@autodesk.com
ME Solutions Thom Tremblay Autodesk - Dallas, TX thom,tremblay@autodesk.com	**Industry Solutions Manager** Sarah Krasley Autodesk - San Francisco, CA sarah.krasley@autodesk.com

3 Design Requirements

3.1 Vision

The design team's vision is to substantially reduce the 50 million tons of electronic waste that are added to landfills every year by developing a broad class of fully recyclable electronic products characterized by quick disassembly and effortless separation and disposal of the components by the user at end-of-life. Additionally, the products will take advantage of functional modularity to distinguish themselves from competitors in the marketplace.

3.2 Functional Requirements

Requirements	Metric	Rationale	Level achieved	Originates from…
Can be fully dis-assembled in a short amount of time	Short = 90% of users should be able to disassemble the whole product within 2 minutes	Although only a one-time inconvenience, long disassembly times will dissuade adoption by new users.	100%	CFP
Can be easily upgraded and/or repaired	Key components are changeable in 1 minute.	Easier upgradability reduces service and warranty costs. Also, design for upgradeability accommodates changing market and customer requirements and increases product configuration flexibility on the manufacturing line. Greater use of industry standard components reduces inventory.	100%	Functional
No tools are required for disassembly	There are 0 fasteners that require tools to open (e.g. screwdrivers, wrenches, etc.)	Minimizing physical and mental barriers are important for motivating users to disassemble the product.	100%	CFP
Visual instructions are uncluttered	Instructions should not have more than 3 boxes and should be simple graphics rather than photographs	Minimize user frustration in the disassembly process	90%	CFP
Minimize number of disassembly steps	Limit number of steps to 10	Reduce the user's barrier to performing disassembly as much as possible	100%	Functional

PCB components should be as integrated as possible to reduce the number of parts that the user must remove	Hardware should not be composed of more than 10 distinct parts	Reduces the number of parts that the user needs to handle	100%	Funky
Minimize the number of individual parts that must be disassembled at EOL	There are no more than 8 separate components that are handled by the user during disassembly	Users will be frustrated by having to further disassemble components that they have already removed	90%	Functional
User can easily recognize which materials are recyclable and which require special handling	All components must inform the user of how they should be disposed of. All of the metal components are recyclable without the need for paint stripping or coating removal.	Will ensure that materials are disposed of properly and reduces the recycler's burden of sorting	50%	CFP

Table 1 *Functional Requirements*

Constraints

- Product can withstand forces, temperatures, liquids, and climates that other products in this category normally encounter.
- Disassembly mechanisms do not affect the product's functionality before EOL.
- Product must meet mandatory legal safety requirements.
- Disassembly mechanisms should not be accidentally activated during the product's use.
- An approximate lifetime of a computer is two years – 50% of the design's original components (including casing) should function after four years.

3.3 Physical Requirements

Requirement	Metric	Rationale	Level achieved	Originates from
Design provides a permanent means of identifying materials and components using standard (national) identification markings to help avoid contamination in recycling	90% of users and all recyclers can correctly identify component/disposal types	Users are discouraged from recycling when they don't know what is recyclable or what to do with their recyclables	50%	Given
Product components can be separated into single-stream recyclable and non-conventionally recyclable (NCR)	90% of users can physically separate single-stream components from "special handling" components	Users are discouraged from recycling when they don't know what is recyclable or what to do with their recyclables	50%	Given
Design minimizes number of materials that must be down-cycled or separated	Individual components are made of no more than one material. Wherever possible, the materials choice for 'active' components should match the materials that they are combined with. This means two different plastics shouldn't be mixed and stickers or paints shouldn't be used.	"Monstrous hybrids" – components made of inseparable but distinct materials – are either non-recyclable or can only be down-cycled	80% PCBs are still the same.	Dark Horse

Table 2 *Physical Requirements*

Constraints

- Product durability is not compromised by material properties.
- No accidental disassembly occurs
- Product utilizes standard connection types so it can integrate with external electronic components.
- All product components must be recyclable in the existing recycling ecosystem.

Assumptions

- The product can compete with other products in its category both economically and functionally.
- Product size is comparable to sizes of other products in its category.
- Completely non-destructive disassembly is possible with an optimized process.

4 Design Development

4.1 Understanding the E-Waste Problem

What is the lifecycle of a typical consumer electronic product?

What does the solution space for recyclable products look like?

What kind of green products are there?

Making products more recyclable touches every aspect of the product lifecycle, from manufacturing to transport to energy use, not to mention product-consumer interaction and the process of recycling itself. During the course of this project, the design team dedicated a lot of time to defining the problem and solution space of electronics recycling by conducting research, benchmarking, and needfinding within various aspects of the electronic product lifecycle (Figure 3).

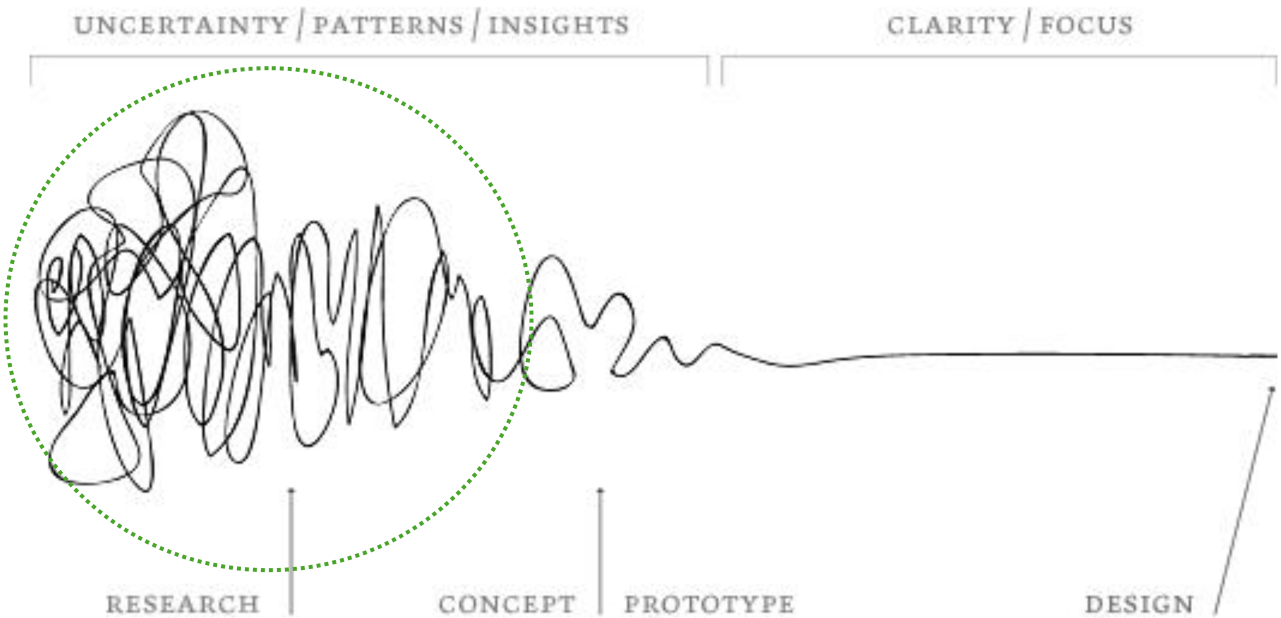

Figure 3 *Initial phase of the design process: research*

The needfinding and benchmarking process began with research into the basics of recycling; the legal regulations, existing organizations and green products, as well as recycling technologies. In this sense, the team sought to understand the needs of the four key stakeholders in the product lifecycle: designers, recyclers, manufacturers, and consumers. As the project progressed and the team's prototypes became more refined, research and needfinding focused more on product-level sustainability (e.g. materials, life-cycle analysis guides, and design for sustainability methods). Overall, the insights gained from the team's extensive research, experiments, and interactions with potential users, experts and stakeholders fueled the initial stages of the team's design development. The following chapter, "Understanding the E-waste Problem," illustrates the team's research methods and key findings.

4.1.1 Needfinding

There are multiple phases in the product lifecycle, each of which involves a variety of inputs and outputs and affects various stakeholders. Each of the four key stakeholders - designers, manufacturers, consumers, and recyclers – has a unique set of needs that drive their relationship with the product during its lifetime (Figure 4). The design team believed that understanding these needs would help identify the main problem areas of electronics recycling and thus guide the team in focusing on a specific problem for the project.

Figure 4 *Product Lifecycle*

The Designer

How does design for sustainability factor into the design of an electronic product? In order to help answer this question, the team spoke to a few designers at Apple, Inc. to better understand what drives designers of electronics products. Key findings from this interview are:

- "Green" is a nice-to-have, but not a need-to-have for most consumers. While it may serve as an additional selling point, functionality takes precedence.
- Functionality, robustness, and aesthetics typically take higher priority than recyclability or design for disassembly.
- Balancing the above characteristics is difficult and there is never a "right way" to do it.
- Designers are also influenced by manufacturing capabilities and government regulations

DESIGN FOR DISASSEMBLY

Autodesk's project prompt to design for consumer-level disassembly (see Appendix A) guided the team towards studying disassembly methods. The team discovered several different approaches – design for repair, design for upgradability, design for longevity, design for clean manufacturing – that could potentially influence the final product design. One method that influenced our product development most was Design for Disassembly (DfD). DfD is a design process that underlines the need for easy recovery of products, parts and materials when a product is disassembled. Some of the general guidelines for DfD that the team found particularly applicable to the project were:

Figure 5 *The complexities of design for disassembly*

Key lessons learned

- Use detachable joints such as snap, screw or bayonet instead of welded, glued or soldered connections.
- Use standardized joints so that the product can be disassembled with a few universal tools, e.g., one type and size of screw. Instruct the user how to open the device non-destructively. Mark separation points clearly.
- Position joints so that the product does not need to be turned or moved for disassembling.
- Fracture is a fast disassembly operation. Connections can be design to break as an alternative to removing fasteners.

EVALUATING ENVIRONMENTAL IMPACT OF PRODUCTS

A variety of methods are currently used to evaluate the ecological performance (materials and processes) of a product. For example, standards such as Cradle-to-Cradle[2] and EPEAT[3]. have been established to determine the ecological impact of products and production processes. Designers also employ lifecycle analysis tools, such as GaBi4 and Okala5, during the early concept-phase to try to optimize the sustainability of their design.

The design team studied ecological performance metrics and systems to understand the role that Autodesk products have in prototyping "green" products. Although there are at least a dozen very reliable metrics, no one single solution is dominating the market place at the moment. Green design currently employs tools that rely on a "spreadsheet" form that link raw materials and components with the waste streams they generate. Presented in Table 3 are some of the design tools, labels and standards currently available.

2 http://www.mcdonough.com/cradle_to_cradle.htm

3 http://www.epeat.net/

4 http://www.gabi-software.com/

5 http://www.idsa.org/whatsnew/sections/ecosection/IDSA_okala_guide_web.pdf

Green Product Development Tools		
Phase	**Tool**	**Description**
Concept	EcoDesign Strategy wheel (LiDS Wheel)	Presents eight design strategies. The EcoDesign strategy wheel gives a clear understanding of possible strategies for new product design.
Concept	EcoDesign Checklist (Breznet and van Hemel)	Ecodesign checklists consist of a set of questions concerning the product's life cycle that can be used to identify its environmental strengths and weaknesses**.**
Design	MET Matrix	The MET matrix shows used materials (M), consumed energy (E) and generated toxicity (T) in the different stages of the product life cycle.
Design	Eko 99	Gives a single-score metric to evaluate rapidly the environmental load in different parts of the product's life cycle.
Design	Autodesk Ecotect Analysis	Green building software analysis tool that helps analyze multiple design alternatives.
Prototype	Solid Works Sage	Software analysis tool that helps give a comprehensive view of the environmental impact of a product. Takes into account carbon footprint, air, water, energy used in manufacturing.
Product	MIPS	A metric that calculates the gauging material input per service unit and identifies the "ecological rucksacks" that products and services carry when they arrive at the consumer.
Product	LCA	Life Cycle Assessment, calculates the whole product life-span impact on environment. Very precise. Included in different software (GaBi, SimaPro)
Labels and standards		
Product	EMAS	The EU Eco-Management and Audit Scheme is a management tool for companies to evaluate report and improve their environmental performance. *http://ec.europa.eu/environment/emas/index_en.htm*
Product	ISO 14000	Standard that requires a certificated company to demonstrate commitment to continual improvement in environmental performance and to have an environmental management system that covers all significant environmental aspects or effects that it can influence. *http://www.iso.org/iso/iso_14000_essentials*
Product	Energy star	The Energy Star Office Equipment Program is a self-certification program initiated by the US Environmental Protection Agency. It programe aims to reduce energy consumption in electrical goods by putting in place measures to reduce energy wasted during idle.

Table 3 *Tools for environmental impact analysis*

Role of Lifecycle Tools during Product Development

The Green Electronics Council (GEC) has created a rating system called EPEAT (Electronic Product Environmental Assessment Tool) that evaluates products on 51 environmental criteria in eight categories, including materials use, design for end of life, and packaging. The EPEAT and the team's product components benchmarked against it can be found in Appendix C.

These different tools, labels and standards did not help the team that much in building the product. However, they provided the team with useful backup for some of its original design assumptions. All the methods that included calculating proved to be very difficult. For laptops, the biggest environmental effects were very different depending on the calculating mechanism. Some of the methods valued the transportation very high, others use & power consumption. The tools wouldn't have helped us in narrowing down our approach. There is clearly a need for a tool that would help evaluate the greenness of a product early on in the design product.

Best and Worst Practices in Green Products and Modular Products

Electronic products can be "green" in as many ways as there are definitions of the word. For example, a product can be energy efficient, made of recycled materials, completely non-toxic, reusable, etc. During the benchmarking process, the Autodesk team sought to learn about existing designs and services that are manufactured with end of life in mind. In addition to existing green products, the team wanted to underline some existing bad practices within the consumer electronic industry (Table 4, Table 5).

GOOD PRACTICES	
	**GreenHeart by Sony Ericsson** • In-phone manual replaces paper manual, reduced packaging • Unwanted (toxic) substances eliminated from product design and manufacturing process • Energy-efficient display,waterborne paint → 15% CO2 emissions decrease
	**MacBook by Apple** • Many toxins are eliminated, such as chlorofluorocarbons (CFC), mercury, arsenic, polyvinyl chloride (PVC), and brominated flame retardants (BFR) • Unibody enclosure is formed from single piece of recyclable aluminum • Display is made of recyclable glass • More energy efficient than older MacBooks • Reduced packaging
	**Reclaim Phone by Samsung** • Made from 80% recyclable materials • 40% outer casing made from bio-plastic material • PVC free, nearly BFR free • Packaging made from 70% recycled materials
	**PS/2E by IBM** • Used many components from ThinkPad line • Composed of recycled plastics • Designed to be easily recycled at EOL • Energy efficient (first Energy Star compliant personal computer)

Table 4 *Green electronics: Examples of good practices*

BAD PRACTICES	
	**<u>Disassembling the product</u>** **Apple** has its own takeback initiatives and national collective take-back programmes. However, the iPhone is hard to disassemble and requires three special tools to do it. This also poses privacy issues as the consumer can't access the memory card easily.
	**<u>Energy efficiency</u>** **Nintendo** game consoles are not subject to Energy Star Program, unlike virtually all of the other gaming market equivalents.
	**<u>Greenwashing</u>** Bamboo is the most sustainable raw material there is: it grows very fast. However, **Asus U6** is not really an "eco-friendly" laptop: it's more of a design statement than a planet-saving option.
	**<u>Hazardous Chemicals</u>** **Samsung Silvercare** cleans and sterilizes clothes with microscopic particles of silver, thereby eliminating the need for detergent and keeping soapy water out of your local reservoir. However, the possible side-effects of nanosilver are unknown, which makes Silvercare the only washing machine to be regarded as a pesticide by the EPA.

Table 5 *Green electronics: Examples of bad product practices*

Part of Autodesk's challenge is to design a product that is modular in addition to being recyclable. The team therefore researched existing modular products in order to better understand potential mechanisms for achieving modularity, the results of which can be found in Table 6.

MODULARITY	
 **ROBOTIX** Modular motorized robotics set for children.	 **LEGO** Modular construction toy consisting of bricks that can be assembled in numerous ways and then disassembled.
 **K'NEX** A construction toy system consisting of interconnecting plastic rods and connectors.	 **SMART CAR** A highly modular, energy efficient vehicle.
 **BUG LABS** BUG is a collection of electronic modules one can easily snap together and program to make any device wanted. It is open source.	

Table 6 *Examples of Modularity*

The Manufacturer

There have been several notable regulations implemented in the last decade that pertain to products end-of-life: WEEE, RoHS, EuP, and eWaste Recycling Fee. The WEEE (Waste Electrical and Electronic Equipment directive) and RoHS (Restriction of Hazardous Substances directive) became European law in 2003[6]. These two directives set collection, recycling, and recovery targets for many types of electrical goods as well as outlawing certain dangerous substances in electronics. Perhaps most pertinent to our project is the fact that the WEEE places the responsibility for disposal of the waste electronic devices on the manufacturer of the equipment (not the consumer). Furthermore these companies must establish an infrastructure such that the consumer can return this electronic waste to the manufacturer at no cost to the consumer him/herself. Although neither the WEEE or RoHS are federally mandated in the US, certain states (New York and California in particular) adhere to similarly strict state-imposed regulations.

The design team investigated manufacturer needs in response to these regulations by visiting the computer manufacturer Apple Inc. and speaking with an employee that was knowledgeable about their recycling and sustainability practices. The Apple employee noted that manufacturers were becoming increasingly attentive to product end-of-life, not only because appearing to be eco-friendly bolstered the company's public image, but also because of government legislation that made manufacturers legally obligated to accept their products at end-of-life. If the fully recyclable product required new materials, then the manufacturer needed to ensure that a reliable and high-quality supply of those materials was readily available.

The team also benchmarked different take-back programs and recycling initiatives that companies have pursued. For instance, Sony Ericsson provides online instructions on how to back up data and then recycle its phone products. Verizon provides online printable mailing labels for mailing in your old phone to a donation program called HopeLine.

Key lessons learned

- If a fully recyclable product requires special or new materials, manufacturers need a reliable and high-quality supply of those materials.
- Designing for recyclability cannot add significant cost to the product (the definition of significant depends on the specific product and manufacturer's industry). Became a part of the design requirements.
- Designing for recyclability cannot pose a risk to the product's functionality, the consumer's safety, or the company's brand. This became a part of the design requirements.
- In-store recycling drop-off for wireless phones, smart phones, accessories and batteries (some companies will take products regardless of manufacturer or carrier).

The Consumer

The third player in the electronic product lifecycle is the consumer. The team sought to gain an initial understanding of consumer needs by conducting interviews with people both as they were shopping at electronics retailers and taking their trash to recycling facilities. Questions were asked about how often they purchased new electronics, what materials they recycled regularly, if they were willing to pay more for a product that is fully recyclable and how much effort were they willing to invest to disassemble a product.

The data collected from these interviews provided useful insights regarding the role of recyclability in purchasing decisions as well as why people do or do not recycle their electronics. Detailed needfinding notes can be found in Appendix B. The many consumer-facing services concerning the recycling or reuse of electronics were also analyzed (Appendix B).

6 http://ec.europa.eu/environment/waste/weee/index_en.htm

HELSINKI USER STUDY: DISASSEMBLY

In Helsinki, the team ran a quantitative user study in order to learn what people think of recycling electronic products, how people feel taking apart the various joint types, and how they expect the ideal disassembly methods to be. The team began the test by interviewing the users, then testing their disassembly expectations, asking them to disassemble a few products and finally testing their experiences individually (Figure 6). Analysis of participants' behavior helped make the team more sensitive to the issues that users might run into when disassembling an electronic product. The pre-test user expectation sheet and the study procedures can be found in Appendix B.

Figure 6 *Monitoring user reactions to disassembly*

During the winter term the team looked also into different internet communities that provide help to the consumer or otherwise foster a DIY culture. For example, there is a lot of well-executed, crowd-sourced data available for dealing with broken laptops, such as iFixit[7] and Instructables[8].

Key lessons learned

- People are lazy by nature. Disassembly needs to be quick and provide feedback.
- Tools are required, but not everyone wants to use them. This became one of the leading requirements, as we decided not to use any tools in the disassembly mechanism.
- No one reads the manuals. Making the first set of disassembly instructions was hard and took a lot of time – and the results were not that different from the existing ones
- Classifying the pieces is not easy, even when the plastic are marked with the Resin system.
- Smashing things is fun, when allowed.

7 http://www.ifixit.com/

8 http://www.instructables.com/

- Upgradeability is an issue for everyone, and quality of eco-products raises questions.
- Motivations for recycling and disassembling differ a lot amongst consumers. Motivations don't have to necessarily have anything to do with user demographics. This became one of the main ideas behind the business model around the final product.

The Recycler

Electronics recycling is an involved process and the specifics of each process can vary drastically between different recyclers. However, a basic overview of the steps involved is necessary in fully understanding how the design of electronic devices fits into the overall product lifecycle, specifically end-of-life.

Briefly, electronics can be disassembled in two ways: manually, where each product is taken apart by hand, or mechanically, where the product is crushed, separated, ground up, and smelted (this is what usually happens to circuit boards). Once the material types are separated, they can be recycled into new components. A synopsis of the processing activities used in the North American electronics EOL industry based on studies by the Green Electronics Council can be found in Appendix B.

PALO ALTO RECYCLING CENTER

Stanford team members visited the Palo Alto Recycling Drop-Off Center to study what happens at one of the critical junctions in the recycling process: transfer of electronics from consumers' hands to recyclers'. The "center" was essentially an outdoor parking lot with a few trailers or ground areas sectioned off for temporary storage of different items. From speaking to the attendee on duty, the team learned that the drop-off location accepts most items for safe disposal or recycling. Some materials, such as polystyrene (Styrofoam), however, were not accepted. Despite the fact that the facility has designated "limbo" areas for storing materials before they are shipped off to the recycling processing center, the areas themselves were disorganized and it was difficult to determine what items should be stored in which area. Overall, the whole place looked like a jumbled graveyard of obsolete, "dead" products – ironic, since the items were to be recycled (Figure 7).

Figure 7 *Discarded electronic appliances*

STENA TECHNOWORLD

The Helsinki team members visited Stena Technoworld to see how electronics are recycled in practice. The current infrastructure for safe reuse and recycling of obsolete equipment is insufficient and much of the waste is handled inappropriately in facilities that are not equipped to handle hazardous materials. The team learned that phones are not the most problematic devices since there is a pre-existing system in place for them. In addition, the phones contain little material – one large PCB containing more plastic than the average cell phone. Worth noting are the products not seen in the recycling center (i.e they are either in homes or in mixed waste): razors, kids toys, kitchen appliances. Other problematic products are kitchen appliances and copying machines. The Helsinki team also learned that recycling electronic products is still very much manual work and the existing machines are big, expensive and contain a lot of chemical distilling mechanisms (Figure 8). See Appendix D for more notes from the visit to Stena.

Figure 8 *Stena consumer electronics disassembly, phase 1: Manual disassembly of plastics and PCBs*

Key lessons learned

- Phones are recycled well because there is an infrastructure for donation and take-back programs.
- Small, "low-tech" electronic appliances, like razors, mixers and kids toys are the problematic ones, they get easily dumped into the mixed waste.
- Disassemble/separate precious metals and components from complex products w/o losing precious metals.
- There is definitely room for improvement in the interfaces along recycling chain.
- Recyclers need products to be easily disassembled and sorted by material type (plastics, metals, hazardous substances) in order to process them efficiently.
- The current recycling system does not include specific drop-off locations for recycling PCBs. For the purpose of this project, the team assumed that, in the future, an effective way of collecting and processing PCBs will be in place.
- Recyclers need a better way to collect electronics products at end-of-life. Currently, the onus is on the consumer to bring the products to the recycling center.

Conclusions

By analyzing the results of our needfinding in conjunction with continued benchmarking research, the design team was able to clearly define a set of the problems facing the recycling of electronic products:

- Until recently, manufacturers do not design with EOL in mind
- E-waste sent to recycling organizations can still find its way to landfills, usually in developing countries
- Consumers are ignorant of most recycling solutions. Because of this they are content to simply "hold on" to old electronics and store them indefinitely
- Consumers are "lazy" and typically lose interest in a product after it leaves their hands at EOL
- The majority of the material in most electronic devices is plastic, paper, or metal (or could easily be made of these recyclable materials), but the presence of certain components that require special handling (PCB's for instance) prevent the entire device from being easily recycled

- Recyclers don't extend a hand to the consumer – the two parties operate in more or less separate realms
- Donation rates for cell-phones and other widely-collected consumer electronic devices are very low

These problems can be boiled down to a very simple one: There is an enormous gap between the consumer and the recycler. Furthermore, this gap is often stretched to a chasm by certain consumer behaviors – namely, the lack of a significant percentage of products at EOL reaching the recycler from the consumer. In the product lifecycle, the consumer was identified as a bottleneck in the larger recycling process. A combination of consumer ignorance and "laziness" prevents the products from reaching the proper recycling facilities. Some consumers throw old devices in the trash, but many simply leave them in their garages and attics. Thus, in developing a final product solution, the team would have to address the following challenges.

Design Challenges

>> LACK OF E-CYCLING AWARENESS & ACCESSIBILITY.

Consumers know almost nothing about recycling past the fact that bins are labeled "paper," "plastics," and "cans." A glaring omission in this list is, of course, "electronics." In this sense, in-home recycling offered no easy avenue for electronics and thus most consumers do not know what to do with old electronics. A few are aware of recycling drop-off centers, but most are unlikely to drive long distances to recycle.

>> DISASSEMBLY OF ELECTRONICS IS DIFFICULT.

The vast majority of electronic devices are not designed for disassembly, and consequently, taking them apart is a difficult task for recyclers, and especially for the average consumer.

>> MANY ELECTRONIC DEVICES ARE NOT MODULAR.

There is little emphasis on modularity in the electronics world. Parts are not reusable and thus the product only lasts as long as its weakest link. Additionally, there is no standardization of parts across the industry, which makes modularity between different devices or manufacturers impossible.

4.2 Exploring the Relationship between People and Electronics

Figure 9 *Consumer & Electronics*

http://www.sicoret.com/si/images/consumer-electronics1.jpg

4.2.1 Overview

Research and needfinding helped the team focus on a key issue within the greater problem realm of e-waste: the communication gap between consumers and recyclers. Although there are many different ways to address this problem, the design team found that one of the most suitable and effective ways to increase the recyclability of the product was to have it be disassembled by the consumer (Figure 9) (see brainstorm notes in Appendix B).

Not only was this the subject of the original prompt (Appendix A**),** but also the result of research that led the team to identify the consumer as the weakest link in the chain of the product's life. With a more intelligent product design that ties the consumer more directly into the recycling process, the team hypothesized that more EOL products and components would find their way to recyclers. The design team felt that this avenue for change was relatively unexplored, and as such, was ripe with opportunity.

The first step in exploring this solution space of consumer-driven product disassembly was to better understand consumer interactions with electronic products. Although needfinding and the electronics disassembly user study provided a good preliminary understanding of consumer behavior, the design team wanted to establish a deeper comprehension of user needs with regard to the following areas:

Guiding Questions

Design for Disassembly

- What functional and physical design requirements are necessary to establish a user-centered disassembly process?
- What design elements allow users to easily disassemble a product without tools or knowledge?

Motivation to Recycle

- What motivates users to recycle or disassemble products?
- What is the “tipping point” that will either drive or deter a user to disassemble and recycle?

The design team proceeded with this investigation by building prototypes of potential design solutions and testing them with users - phase two in the overall design process (Figure 10). This new knowledge of consumer needs would be key to developing a set of design criteria for the team’s final product solution.

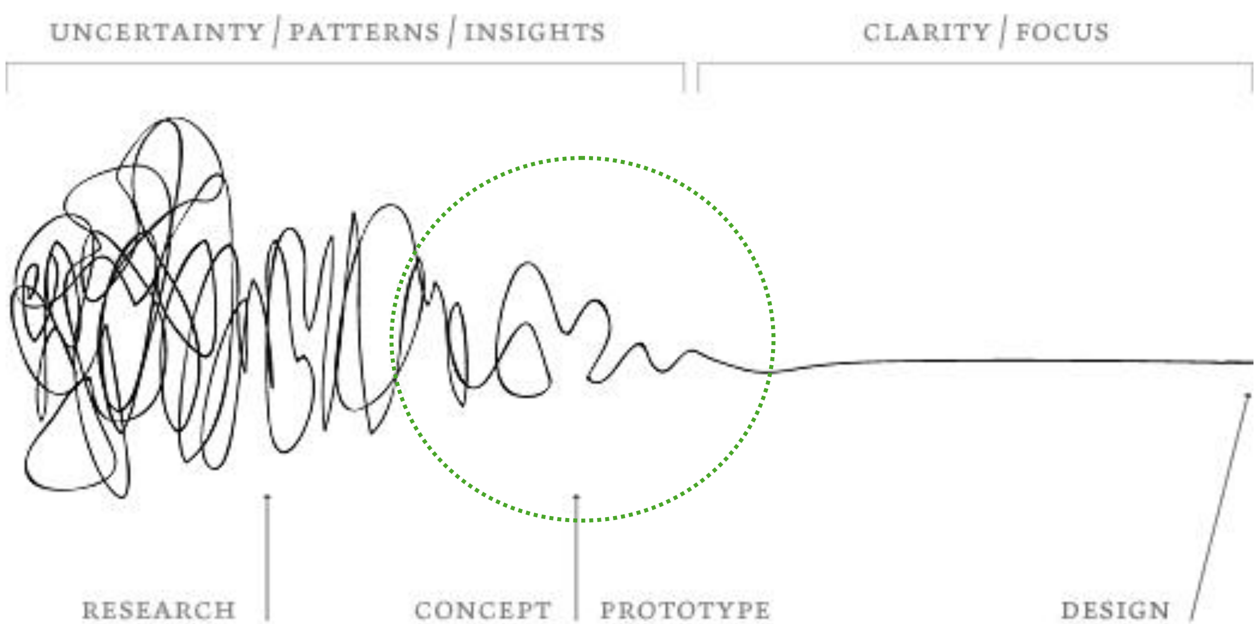

Figure 10 *Next phase in design process: prototyping and testing*

4.2.2 Understanding Disassembly by Consumers

There currently exist guidelines for designing for disassembly (DfD) by recyclers or manufacturers, professionals trained and equipped to break down products[9]. But consumers are not professionals, nor do they have access to specialized disassembly tools; they are a different user with radically different needs. As such, it was critical that the design team develop a set of DfD guidelines geared specifically toward consumers. The results from research and needfinding led the design team to two seemingly obvious realizations:

1. **Most products are not recycled simply because they contain certain NCR components (such as circuit boards) that are not easily accessible.**

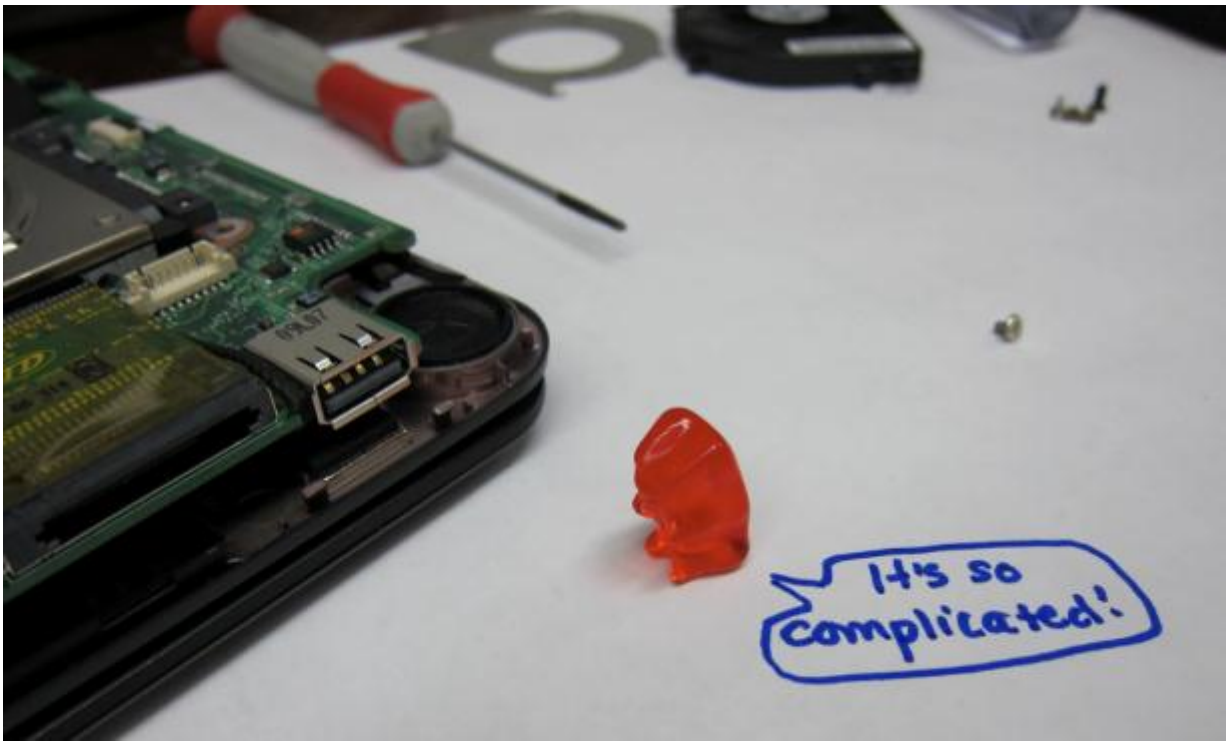

Figure 11 *It is difficult to recycle electronics*

9 http://www.activedisassembly.com/guidelines/ADR_050202_DFD-guidelines.pdf, http://www.idsa.org/whatsnew/sections/ecosection/IDSA_okala_guide_web.pdf

2. People do not disassemble products because they are lazy (lack of interest or motivation), lack the tools, or lack knowledge.

Figure 12 *Consumers are "lazy"*

http://www.sortoutstress.co.uk/sos_images/features_lazy.jpg

A solution to both of these problems is one that also answers the question,

How do we design a user-friendly disassembly process?

The team established that five important functions needed to be addressed to answer this question:

- **[1]** Instructions/labeling for disassembly
- **[2]** A method for easily opening/disassembling the device (no tools required)
- **[3]** Locating the PCB
- **[4]** Removing the PCB without tools and with minimal effort
- **[5]** Classifying and disposing of components after disassembly

The team built and tested two prototypes – called Critical Function Prototypes (**CFP**) – to explore how the above critical functions might be embodied in a product solution, as well as how users react to such a solution.

Sugar Glue Cell Phone

How can we design a product that requires no tools or prior knowledge of electronics to disassemble?

The first CFP, Sugar Glue Cell Phone, was designed to test one possible solution that meets user needs by incorporating a no-tools required, easily disassembled joint type (function **[2]**) and clear component labeling for materials classification (functions **[5]**).

Need	Opportunity
Disassembly requires too many tools and too much labor	Sugar glued joints can be disassembled easily in the water
Classify the different materials is difficult,	Color coded components can be easily classified

Table 7 *How the sugar glue cell phone addresses user needs*

DESIGN DESCRIPTION

The Sugar Glue Cell Phone prototype is a cell phone designed to eliminate typical, labor-intensive joint types (such as screws, snap-fits) by using a strong, sugar-based glue to adhere components together. When soaked in water at EOL, this sugar-glue dissolves and the components separate.

Figure 13 *Sugar glue cell phone (held together with clamps while drying)*

The prototype also integrates a method for establishing easy component classification. Since the resin identification codes for plastic inside the parts are too hard to understand (PP, PET, and PVC etc.), the team used color-coded labels. Using different color tapes to mark the different materials could be an obvious way to visualize the materials categories. All the electronics, metal, and plastic parts were respectively marked with orange, blue, and yellow striped tape (Figure 14). People can classify the components for recycling easily by distinguishing the colors.

Figure 14 *Color-coded labels for component classification*

Figure 15 *User-testing the color codes*

The team asked several users to test this new disassembly method by placing the sugar glue cell phone into a water vessel and also to describe their experience at each point during the test. (Batteries were removed for the tests for safety reasons).

PCB Attachment

How can no-tools disassembly be achieved without compromising PCB security?

In order to address the issue of accessing and removing components that required special handling (NCR components), the team designed a second CFP that would test various ways of mounting a circuit board (PCB) to a surface such that it is just as secure as screwing it down, but can also be removed without tools. The team constructed four prototypes for critical function testing, each exploring a different method of securing a PCB to a surface.

DESIGN DESCRIPTION

Figure 16 depicts the team's "twist-to-release" prototype, in which the consumer twists the four wing bolts at the corners of the PCB to slide the board out. Figure 17 shows a magnetically fastened prototype, in which the PCB slides into place and is held secure by a permanent magnet. Figure 18 is an image of a press-fit prototype, in which a user can snap the PCB into or out of spring loaded sockets. Figure 19 shows a "spring-loaded" prototype, in which the user inserts and removes the PCB from a spring-loaded housing.

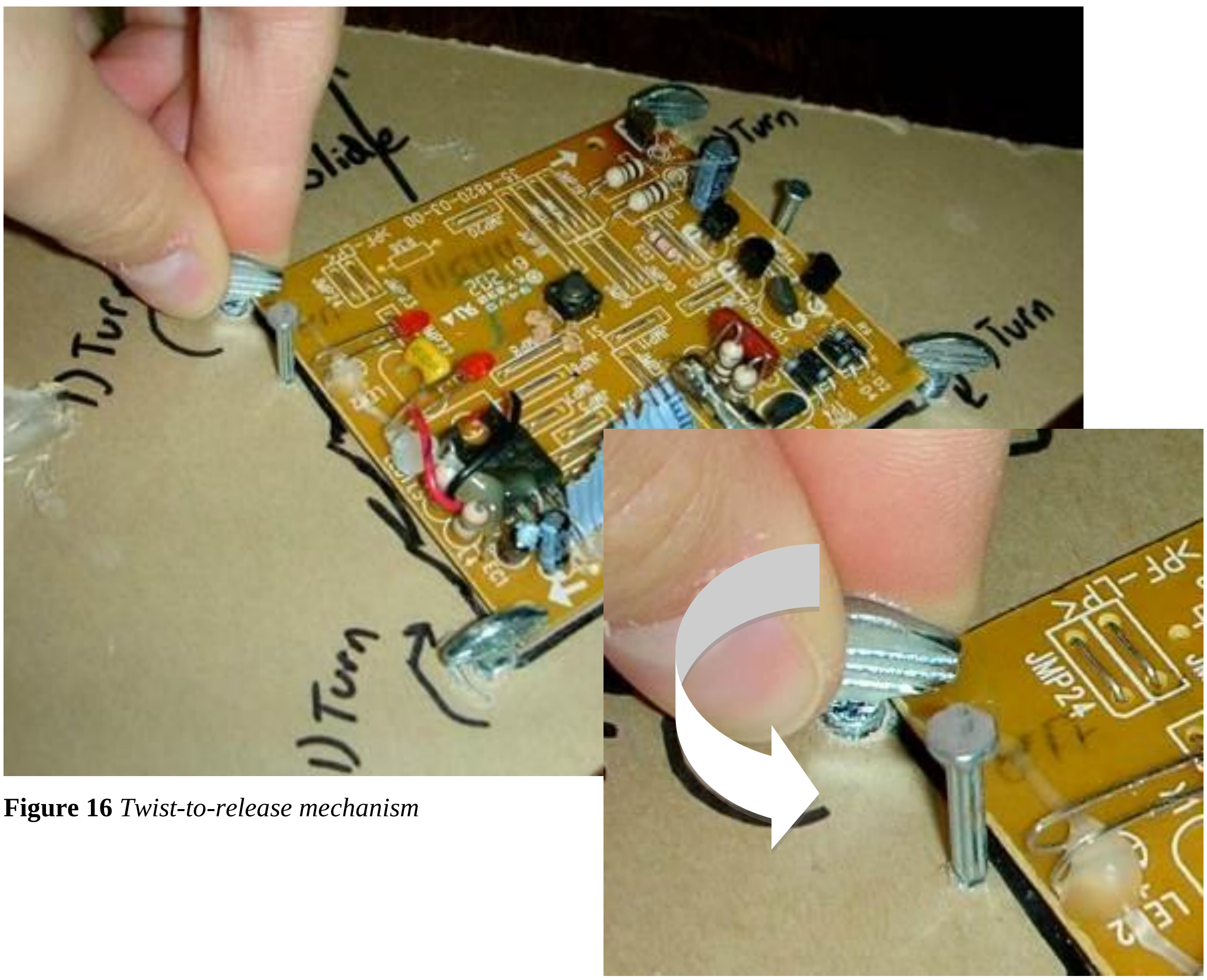

Figure 16 *Twist-to-release mechanism*

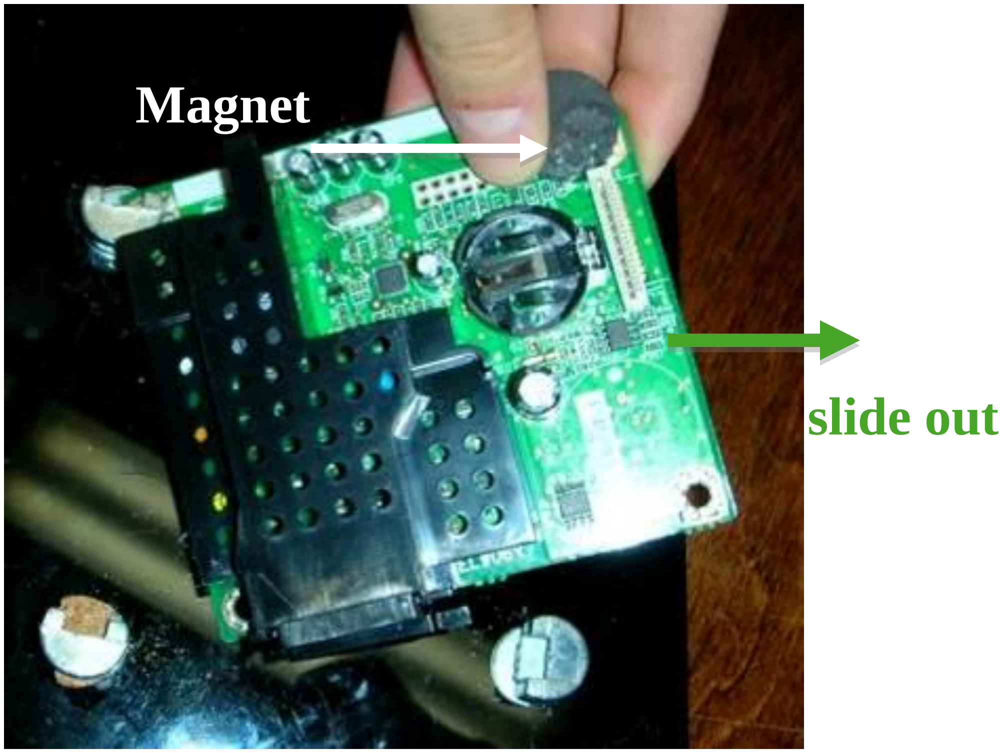

Figure 17 *Magnetic mechanism*

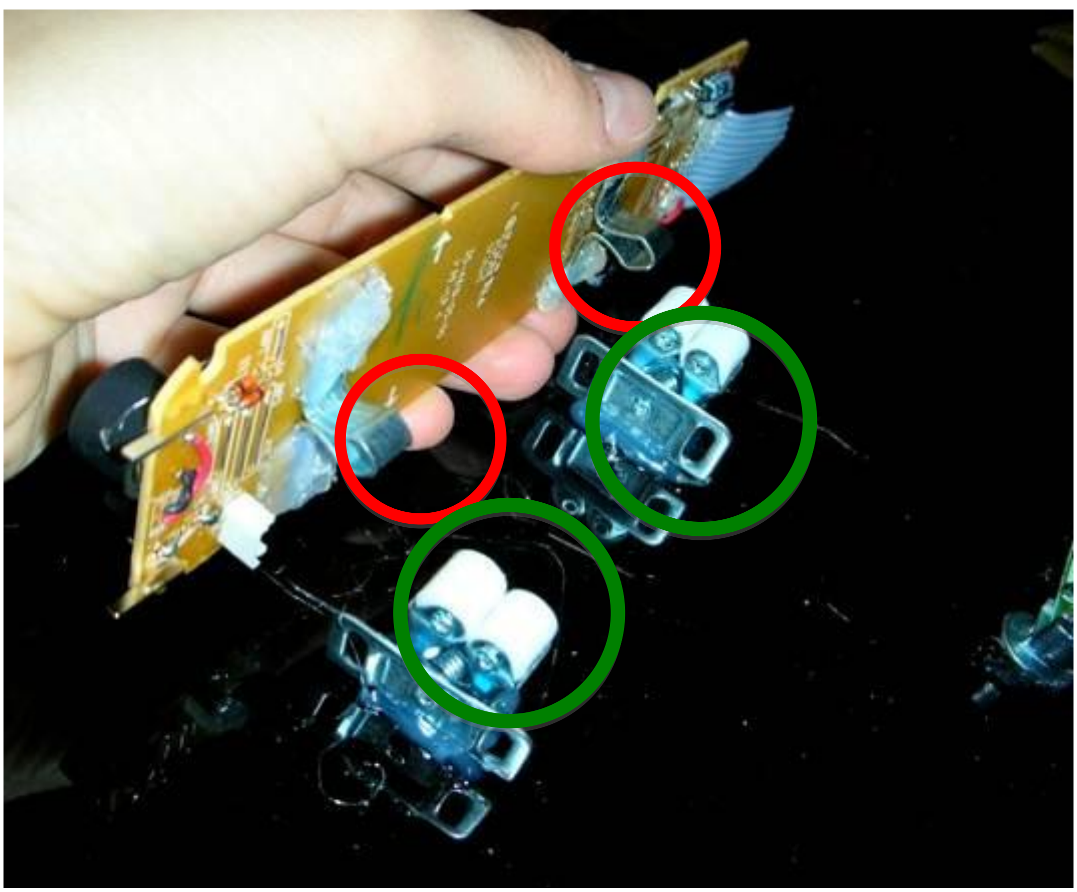

Figure 18 *Snap-fit mechanism*

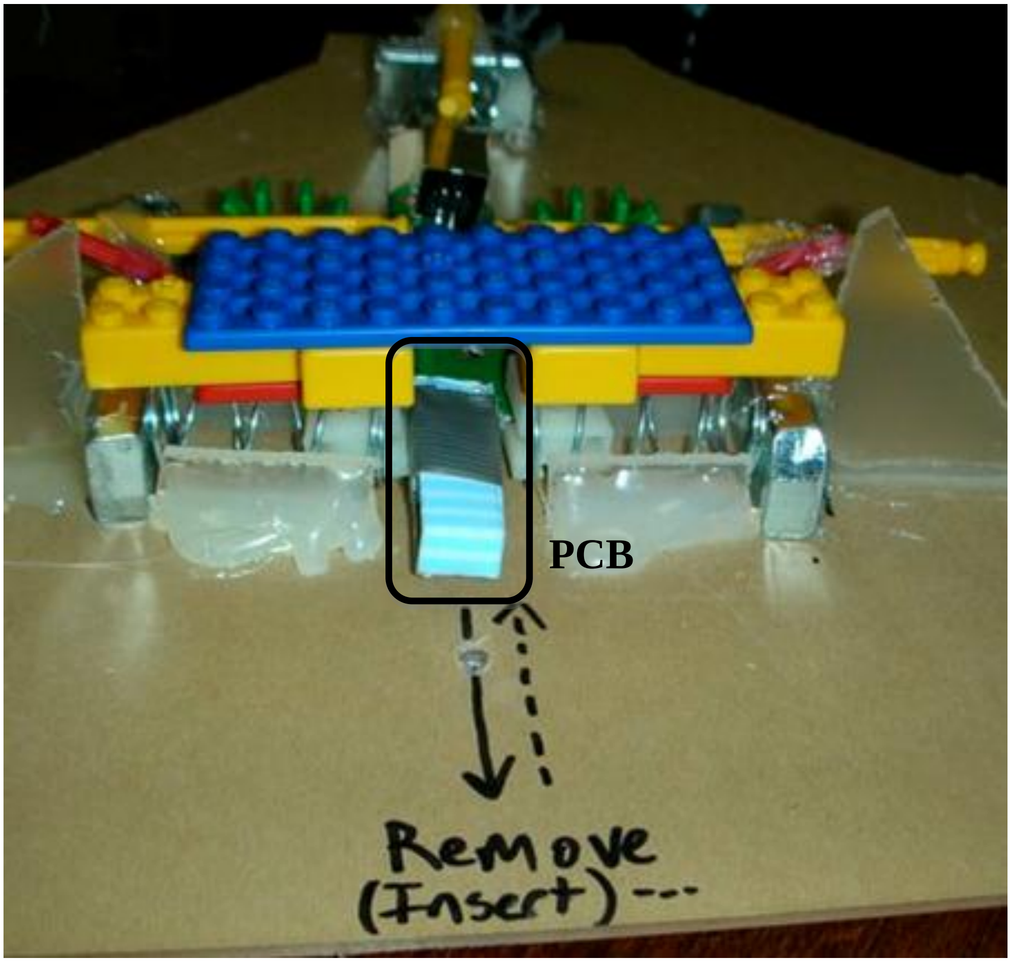

Figure 19 *Spring-loaded mechanism: Push PCB into slot to load, push again and it pops out.*

User Testing

Each of the four prototypes was handed to multiple users in order to get feedback about what consumers liked and disliked about each method of securing the PCBs. Users were asked to rank the prototypes across four categories. The results of the study are in Table 8.

- How securely do you think the PCB is held in place?
- How effortless was it to remove the PCB?
- How quickly could to remove the PCB?
- How simple and intuitive was the process?

	Press-fit	Spring-loaded	Magnetic	Twist-to-release
Security	4 – Wobbly (need lateral supports) - Fatigue problems	2 – requires support on all sides	3 – alignment must be precise	1 – very secure
Ease of removal	2 - Springs too tight (possible damage)	1 – extremely easy	3 – difficult to know how to remove without visual guides	4 – very hard to twist screws in acrylic
Removal Speed	1 – fast, once you understand how to remove PCB	3	2	4 – hard to twist four screws quickly
Simplicity	3	4 – overcomplicated and confusing	1 – no moving parts	2

Table 8 *Ranking different attachment mechanisms*

Key lessons learned

- Users prefer an effortless disassembly. Any required effort can discourage users from completing the process.
- Visual or auditory feedback during disassembly is necessary. Users are not sure if they are removing the PCB correctly, even when they are in fact performing the correct action.
- Visual instructions are an important aid during the disassembly. Some of the prototypes had drawn-out instructions for how to remove the PCB.

Key Conclusions About Consumer Disassembly

Key Conclusions

- **Intuitive disassembly process is key.** Faced with an unfamiliar task, users rely heavily on intuition, and how closely the design follows this intuition is the key to its success or failure.
- **Less is more.** Visual cues are necessary but should as simple and cartoon-like as possible.
- **Users that feel *engaged*** during the disassembly process are more likely to be successful in completing the task.
- **Users prefer an effortless disassembly.** Any required effort can discourage users from completing the process.

4.2.3 Motivation and the End-of-Life Experience

When it comes to recycling, people lack interest and motivation. The design team's research showed that many people resort to the easiest solutions when dealing with old products: they toss them in the trash or keep them piled up in the garage. Therefore, the some incentive is necessary to motivate the consumer toward recycling action. The team hypothesized that, by designing a product that harnesses just the right motivations, more people will be willing to make the extra effort to recycle. In order to further explore the concept of motivation, the team prototyped and tested a number different EOL experiences for consumers.

Seeds Box

How can one inspire the user to disassemble products at EOL?

The team studied professional articles on human motivations, as well as conducted an informal survey on the internet to obtain information from consumers about what motivates them. The team discovered that greatest internal motivators are ones that include responsibility, achievement, pleasure, and surprise. The goal for the Seeds Box prototype was to design something that could be easily disassembled but would also inspire the user to take it apart by harnessing their internal motivations.

Need	**Opportunity**
Most components from the end-of-life products are not sustainable and not easy to recycle.	Sugar glued paper box can be recycled easily
Customers are lack of motivation for disassembling or recycling end-of- life products.	Growing seeds as internal motivation

DESCRIPTION

The Seeds Box prototype takes the form of a cell phone that can be quickly disassembled at end of life without tools and then properly recycled from the comfort of the user's own home (Figure 20). All components are completely recyclable and are joined together using a special degradable adhesive (same as the Sugar Glue Cell Phone prototype). When the phone has reached EOL, it is placed in water for 10 minutes to dissolve the glued joints, after which the individual components are nicely separated (Figure 21). The Seeds Box casing is made from recycled paper with embedded grass seeds that the user can plant at the product's end of life to grow a blooming surprise.

Figure 20 *Seeds box*

Figure 21 *Dissolving seeds box in water*

Dark Horse Prototypes: Reincarnation Box & ReBox

In order to further study user motivation in the EOL recycling process, the design team prototyped an entirely new system for disposing of broken electronics – one in which easy product disassembly is ubiquitous, and consumers receive rewards for recycling. The prototype (actually a pair of prototypes) was designed to fit into a future "take-back" system that would likely arise out of legal mandates – specifically the increasing regulations that place EOL recycling responsibility on manufacturers and retailers of electronic products.

Although the team knew that such a large-system solution would be risky to implement and very likely to fail, it also knew that there would be much to gain if the prototype succeeded. Because of its riskiness, this prototype came to be known as the ***Dark Horse***. With Dark Horse prototype pair, the team sought to explore potential ways to make electronics recycling more accessible and rewarding for consumers.

GOALS

The Dark Horse - Reincarnation Box and ReBox - prototypes are sister devices that accept electronics at EOL, disassemble them for the consumer, and then provide the consumer with a recycling "reward." Both prototypes assumed that a no-tools disassembly product already existed. The goals for these prototypes was to simulate the above-mentioned recycling experience for the user in order to:

- Gain insights into the different aspects of recycling, disassembly, and collection.
- Understand what users are likely and unlikely to do with respect to recycling.
- Explore which rewards for recycling are most likely to elicit "habitual" recycling.
- Better understand materials, specifically plastics and circuit boards

DESIGN DESCRIPTION

REINCARNATION BOX

Figure 22 *Reincarnation box*

The team built an electronics recycling machine, dubbed “Reincarnation Box,” that accepts a broken electronic product, disassembles it, and then melts down part of it and injection-mold it to become a new small product (e.g. toy, keychain). In essence, the product is “reincarnated” through the machine. In reality, the prototype was a “black box” that simulated this process. It consisted of a user interface screen and two slots, one for insertion of the e-waste, and another for dispensing its “reincarnated” form to the user (Figure 22).

Figure 23 *Examples of "reincarnated" toys*

User tests were conducted at a local coffee shop, Safeway grocery store, and at Tresidder Union (on Stanford's campus). For the test, users were handed an old phone and told that it was their broken cell phone and they had just happened upon the Reincarnation Box. No further instruction was given in order to simulate a more realistic encounter with the prototype. The users then followed the displayed steps, and after depositing the cell phone into the machine, were shown how the phone was being recycled and the plastics injection molded into a reward. The on-screen GUI can be seen in Appendix D. The rewards that were given to the user were random toys and keychains purchased from Target – all plastic objects that could potentially be injection molded with recycled materials (Figure 23).

Key lessons learned

- Users value the experience of participating or watching the disassembly process more than they value receiving a reward
- Users want to feel that they are part of the recycling process, or that they facilitate a stage of the process
- Users want to understand the recycling process - Education about recycling can be a strong incentive to recycle
- User tests confirmed users lack of knowledge about recycling
- Convenience of drop-off locations is of utmost importance. Must be at a location visited regularly by user.

REBOX

The ReBox prototype is a recycling box for PCBs that consists of a graphical user interface and a slot in which to discard old circuit boards. The primary assumption for this prototype was that a future recycling system would be able to include a specific collection bin for PCB's. User tests were conducted at a shopping center in Helsinki: the first set of interviews was conducted in the lobby of Verkkokauppa.com, a computer hardware store, and the other in the recycling room of a Finnish retail store, Citymarket. Users were handed a PCB and asked to discard it in the ReBox (Figure 24).

Figure 24 *Testing ReBox with shoppers*

After placing the PCB in the slot, users saw on the interface a video of a PCB being crushed for recycling (simulating the deposited PCB being recycled). After the video, users were given four different reward options to choose from: refund, participation in a lottery, an information sheet on the PCB, and option to donate the refund to a nature preservation group.

Figure 25 *ReBox sitting near other recycling bins*

RESULTS

The team mapped results from interviewed users onto a two-by-two matrix according to their *willingness to disassemble* a product and the type of their *motivation* (Figure 26). ***Internal motivation*** refers to the desire to do things because you want to do them without direct benefit (e.g. feeling of completion, nature preservation). ***External motivation*** refers to doing things because someone else wants you to do it or rewards them for doing it (e.g. refund, legislation). Most of the users studied were motivated by the feeling of finalizing the recycling process and were somewhat willing to disassemble the product by themselves.

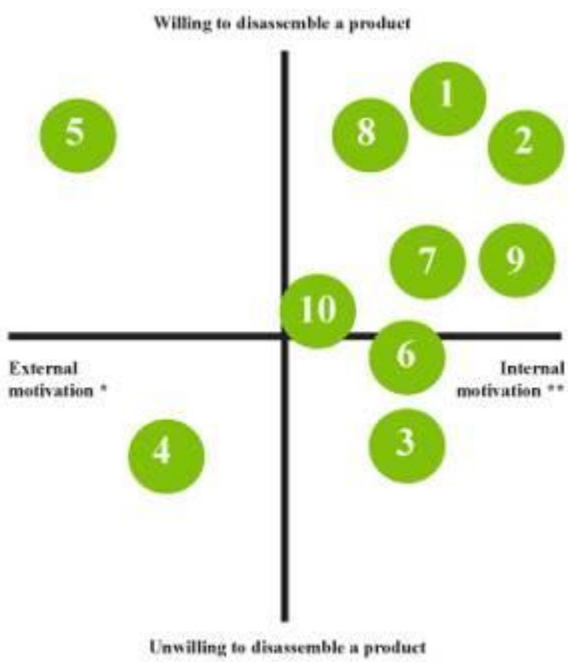

Figure 26 *Graph of user motivations*

Key lessons learned

- Recycling machine should be engage the user and big enough to hold several PCBs at a time. It should be accessible and easy to empty. The machine should communicate that only PCBs can be inserted. The physical recycling machines of today aren't that good: they are big, expensive and require a lot of chemical activities. There would be a lot of room for improvement.
- People aren't concerned with security issues of leaving their PCB's un-crushed. However the PCBs should be protected against theft.
- People are willing to disassemble their old electronics and recycle plastics, metals, and PCB if there is a place to drop them near enough. If the PCBs are crushed and recycled on the spot, manufacturers don't need to send them to other countries to be handled.

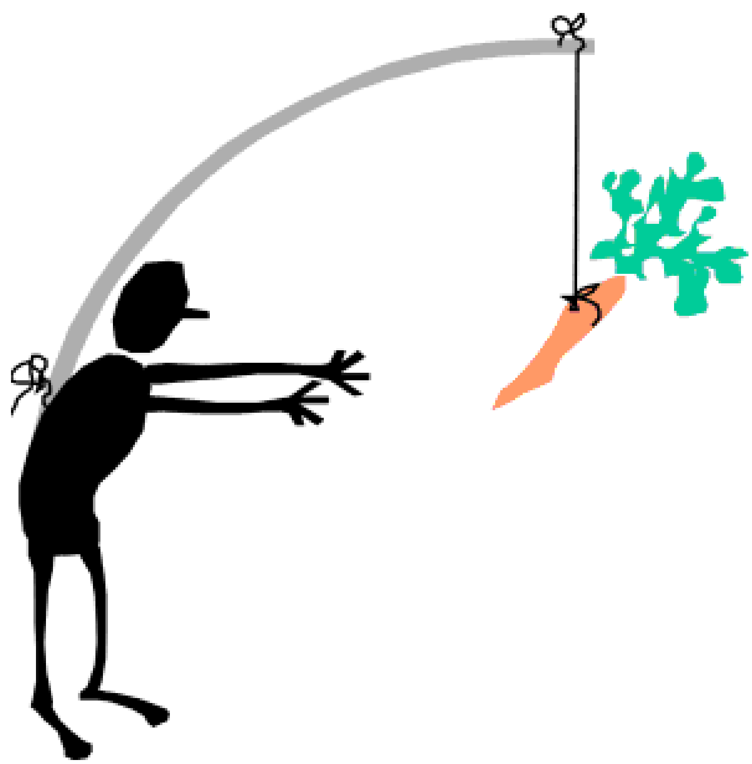

Figure 27 *Motivation*

Key Conclusions about Consumer Motivation and the EOL Experience

Key conclusions

- **Internal motivation** is greater than external motivation. Types of good internal motivation are the desire to learn, to "do the right thing," and to experience something "cool."
- Lack of accessibility and education are the main reasons for consumer "laziness"
- Convenient accessibility of any type of recycling is important to users

4.2.4 Proof of Concept Prototypes

The Dark Horse prototypes tested user motivations around various electronics recycling experiences that were built upon an assumption that an easily disassembled, recyclable electronic product already exists. But such a product does not exist. In fact, it is not clear what such a product would even look like. The next logical step in the team's design process, therefore, was to incorporate the key discovered design requirements into a tangible model of a potential product solution – a proof of concept prototype.

The team constructed two simplified functional system solutions (called **Funky Prototypes**) that embodied the most basic design requirements regarding consumer-level recyclability: ***easy disassembly*** and ***modularity***. By testing the Funky prototypes with users, the team would be able to test the validity and practicality of the design requirements, as well as discover any new requirements that might be critical to future prototype iterations.

Easy disassembly: MP3 Player

Previously, the team defined a recyclable product as one that should be easily disassembled (no tools involved) and quickly separated into conventionally recyclable and NCR components before being reused or recycled at the product's EOL. The MP3 Player Funky prototype was the team's first attempt to fulfill both of these requirements with a physical system prototype.

GOALS

The team hoped to gain two types of insights from building and testing the MP3 player.

[1] Understand what skills, methods, and tools it would take to design and build a product that requires no tools to disassemble.

[2] Better understand the viability of consumer-driven disassembly. By placing the prototype in consumers' hands and observing their behavior in a simulated product end-of-life experience, the team hoped to answer the following questions.

- Can the user figure out how to take the device apart? How difficult do they find it?
- What is the average disassembly time?
- To what extent will the user be motivated to disassemble the device?
- Can the user figure out what to do with the device components after disassembly?
- Would the user be willing to recycle electronics at a local store (Safeway, CVS, etc.)?

DESIGN DESCRIPTION

The team designed a simple MP3 player that can be disassembled and recycled with little effort by the consumer at EOL. The MP3 player consists of a circuit board with LCD screen and buttons (salvaged from an existing MP3 player), a battery, and a case built from acrylic by the team. Users can disassemble the case by twisting the top and bottom portions in opposite directions and then lifting the top casing off of the bottom (Figure 30). The dimensions of the device were purposely exaggerated in order to allow the team to explore no-tools disassembly methods without having to meet any size constraints.

Figure 28 *Closed MP3 Player*

Figure 29 *MP3 player twisting open*

Figure 30 *Lifting two halves apart*

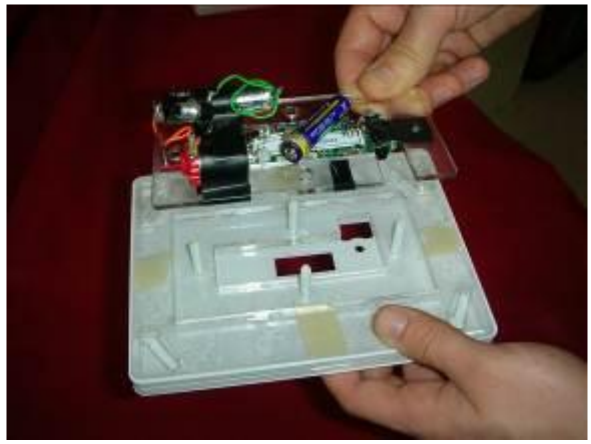

Figure 31 *Removing internal circuitry*

When the case is opened, the internal circuitry is exposed and can be removed from the case by simply lifting it off of four posts **(**Figure 31**)**. The case would be made of recyclable plastic and would be recycled in a conventional recycling bin. Once separated from the case, the circuitry can be deposited directly into an electronics collection bin and then sent to a specialized recycling facility. A more detailed description of the prototype can be found in Appendix E.

User Tests

The team believed that the key to achieving the second goal was to immerse users in a more realistic product EOL experience (i.e. have the prototype "die" in the user's hands during testing). The team accomplished this simulated product death by adding a hidden element to the MP3 player design that would cause the player to stop functioning whenever a button on the back was depressed (see Appendix E for details).

During testing, the user was asked to listen to the MP3 player while shopping and, when they came across a song they enjoyed, press a button on the back of the MP3 player to record that they liked the song. When the user pressed this button, the player would immediately stop functioning and the user would be convinced that it was broken. When users returned the broken MP3 player to the team, the team asked them to disassemble and dispose of the device at a nearby mock recycling booth set up by the student team (Figure 32). The top of the recycling booth displayed a set of step-by-step visual instructions outlining how to disassemble the device and then discard the case in one slot of the booth and the electronic component in another slot. After they "recycled" the MP3 player, users were asked about their reactions to the disassembly/disposal experience.

Figure 32 *Team members attending the recycling booth prototype*

Lessons learned from the Autodesk team's Funky prototypes highlighted the importance of defining and targeting a specific user group. The team had previously explored various user groups but had not yet actually designed a prototype specific to a user's point of view (POV). Establishing a set of distinct POV's would be the next key step in the design development process.

Key lessons learned

[1] The team found that there are a number of ways to achieve no-tools disassembly, but finding one that is intuitive to understand and successfully balances component security with ease-of-detachment is difficult. One way to narrow down the attachment options would be to design for a specific user group. For example, designing for people with arthritis would affect component positioning and the amount of force required for disassembly.

[2] It was clear from user tests of the prototype that the major obstacle users encountered was lack of clarity of the disassembly instructions. Although the team provided step-by-step instructions (photographs of somebody disassembling the MP3 player), the user had difficulty discerning which component they were supposed to remove.

- Visual instructions must be uncluttered (cartoon graphics highlighting only key components and actions are best)
- Disassembly should be as physically easy as possible, but the product should have locks preventing accidental disassembly
- Users DO find it convenient to recycle at places they visit often
- It is important to shield the product's internal complexity from the user during the disassembly process to avoid user intimidation/confusion (usually due to PCB's).
- Product should be perceived as durable despite "no tools" disassembly.
- Users with arthritis have more difficulty with twisting disassembly
- Users' instinctive reaction was to pull the battery out, not the PCB

Green as a by-product: Modularity

One way to achieve easy disassembly is to make the product modular in the sense that components can be reassembled after disassembly. Such a modular product also has the potential to be manufactured easily, upgraded easily, repaired easily, and multi-functional during the product's useful life. A product with these qualities goes beyond "being green" at EOL by offering the consumer real benefits during the product's functional life. The design team sought to explore potential applications of modularity during a product's useful life building and testing a second Funky prototype: the Modular Toaster.

GOAL

The team's goal for the second Funky prototype was to construct a modular product (a toaster) that embodied some of the key applications of modularity: easy disassembly, easy repair, and multi-functionality. By testing the prototype with users, the team aimed at answering a few key questions about modularity and product-specific ecological impacts:

- What are the eco-benefits of modularity?
- How is a modular product designed (both from the manufacturing and user perspective)?
- How does diving deep into the characteristics of one product help the team understand its ecological impact, and how can these lessons be extended to other products?

DESIGN DESCRIPTION

In designing the Modular Toaster, the team focused on how to modularize the heating elements in order to make them easy to repair and to give them multi-functionality. The team designed the toaster case for the heating elements and circuitry such that all components can be easily removed from the main assembly and the heating elements can be swung open to allow toasting in different positions. By unfolding the heating elements, the user can transform the device from an ordinary toaster to a grill. The case was also designed to house the heating elements in a way that reduces heat loss, thus using energy more effectively. Additionally, all the modular components were designed to be on the same level (nothing hidden) in order to enable the users to replace the broken component intuitively (Figure 35).

Figure 33 *Modular toaster, folded*

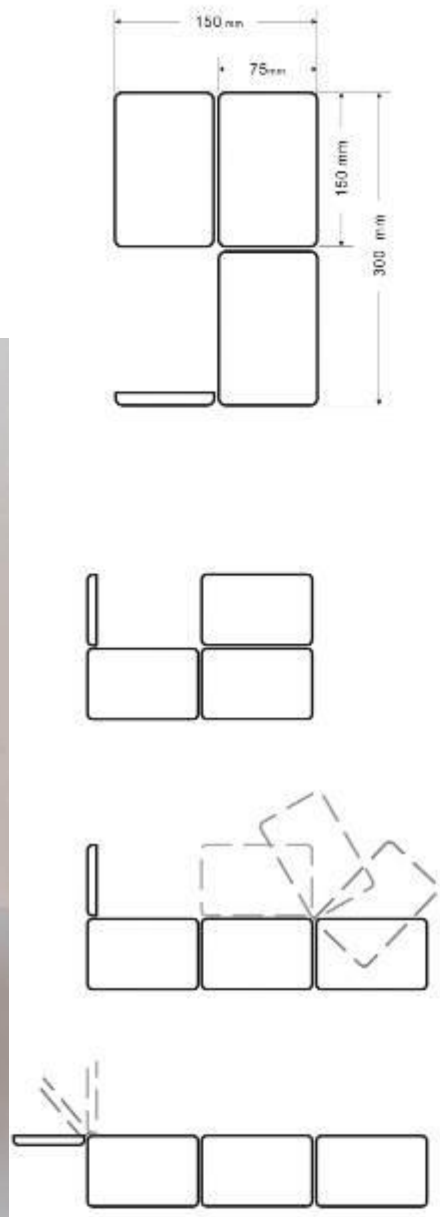

Figure 34 *Graphical depiction of toaster transformation*

Figure 35 *Modular toaster, unfolded*

Key lessons learned from prototype construction

- Wire connections make the designing problematic and restrict the modularity.
- Safety and insulating materials are important. The product needs to be designed so that the consumer does not shock himself. If repaired incorrectly, the system wouldn't allow you to plug it in. There could be a way to show which part is broken.
- PCB and other components need to be easy to remove, however, PCBs shouldn't be taken out accidentally.
- If designing a product with heating elements, the design needs to include space or some eco-friendly material for insulation (not foam).

Key lessons learned from user testing

In order to know how the users would value the application of modularity, the team tested the prototype with some users with different lifestyles. The main findings were listed as follows:

- Younger people are more willing to accept the multi-functional toaster since it can be used in a larger variety of functional contexts while simultaneously saving space.
- For some people who never used toaster before probably still unwilling to try this multi-functional toaster.
- Component modularity seemed intuitive for users, so the goal of facilitating disassembly and reparability were achieved.
- Almost everyone has used a toaster. Still, commercial toasters are almost identical. People don't understand that toasters have PCBs in them.
- Multi-functional modularity in consumer electronics is hard to achieve without a feeling of watching an infomercial.
- Standardization of the components and joints across industry is important in order to achieve better modularity.
- Measuring energy efficiency is not intuitive and the metrics are not clear. Metrics should be presented in a way that you understand it without previous knowledge

Conclusions: Honing in on a Final Direction

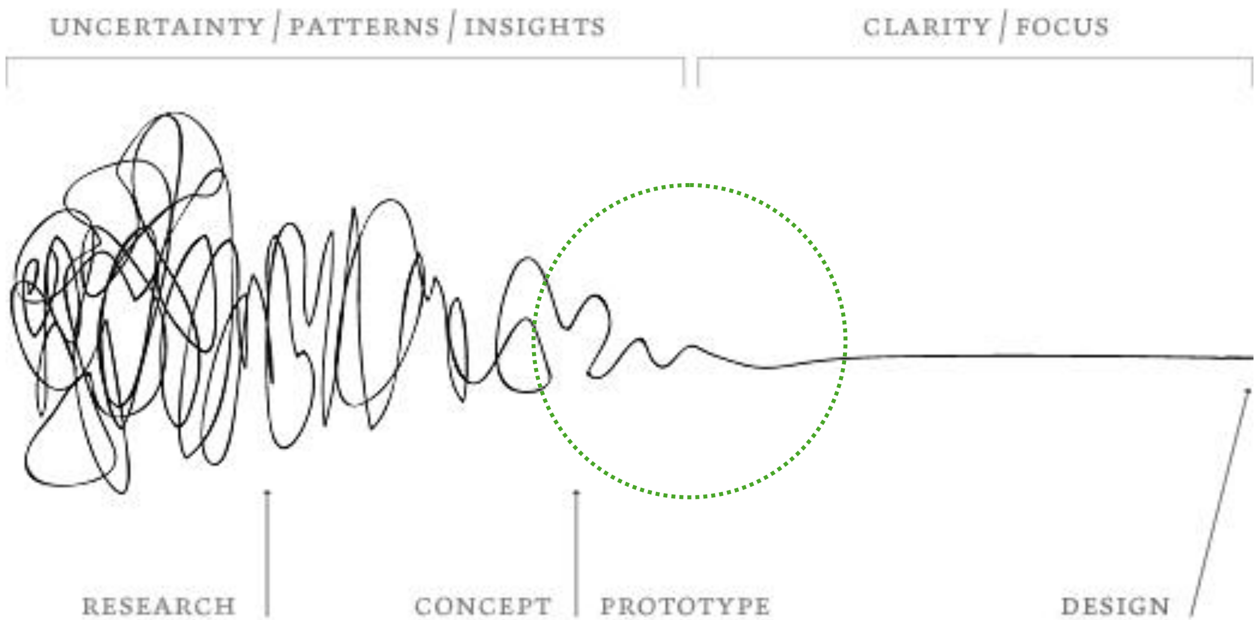

Figure 36 *Next step in the design phase: focusing on a solution*

CONVERGENCE: Defining Key Lessons learned

The Stanford and Finnish design students met in Helsinki in February 2010 to discuss how the project could begin to converge. The teams sought to use the knowledge gained through prototyping, as well as the given and discovered design requirements, in order to choose a final product solution. As mentioned previously, the team's vision was to develop a consumer electronic product where the findings could be applied to a broader set of electronics. Therefore, the design team focused on developing a set of lessons that could be extrapolated to a larger market, rather than designing one particular product for one particular user group.

1. Recyclability by itself is not a strong enough selling point to distinguish the product within its product category.

This was the design team's first critical insight. User testing and needfinding indicated that the average user was not willing to pay more money in order to receive a fully recyclable product. In addition, users indicated that under no circumstances should recyclability lead to a loss of the product's functionality or durability. Indeed, there exists a market segment that is willing to purchase products simply because they are more eco-friendly, but this market segment is small.

Therefore, the design team concluded that in order to achieve widespread adoption of recyclable products, the recyclability of the product must be presented as a *byproduct* of some other design element, and not as a main selling point. The device itself must have some strong fundamental value to the user other than recyclability. The team hypothesized that this strategy would allow a fully recyclable product to reach a wider set of consumers.

2) An intuitive, no-tools disassembly method, clear component labeling, and uncluttered visual disassembly instructions are imperative for achieving consumer-level recyclability.

After talking to electronics consumers, the team quickly discovered that design for consumer-level disassembly must be drastically different from design for professional, recycler-level disassembly. Such a design must be at the extreme end of simplicity and effortlessness if it is to be conducted by people who lack interest and knowledge. Therefore, the team's final solution must incorporate the following design criteria:

- Requires no tools to disassemble
- Clear component labeling (material type)
- Uncluttered, cartoon-like graphical instructions
- Intuitive disassembly process that requires less than two minutes to complete
-

3) Component modularity is a feature that can deliver added value to the user/recycler/manufacturer, and be "greener" at the same time.

The team recognized component modularity as a characteristic that could deliver fundamental value to each of the stakeholders in the recycling ecosystem (users, recyclers, and manufacturers), while reducing e-waste at the same time.

For the user, component modularity offers long-term cost savings. Instead of having to replace or repair the same product multiple times when it breaks down, a modular device would allow the user to swap out blocks of components when necessary. This system works well not only for repairs, but also for upgrades of components when they become obsolete. The byproduct of this system is an extended lifetime for the device, and a reduced amount of e-waste (instead of throwing out entire products, only component modules are being disposed of).

For recyclers and manufacturers, modularity allows for easier assembly and disassembly of products. This is, of course, dependent upon the specific design of the modules and how they fit together within the product, but in principle, modularity offers advantages for both assembly and disassembly. There is also the possibility that modularity can lead to an increased standardization of parts for the manufacturer, as modules should be interchangeable for the same product over time.

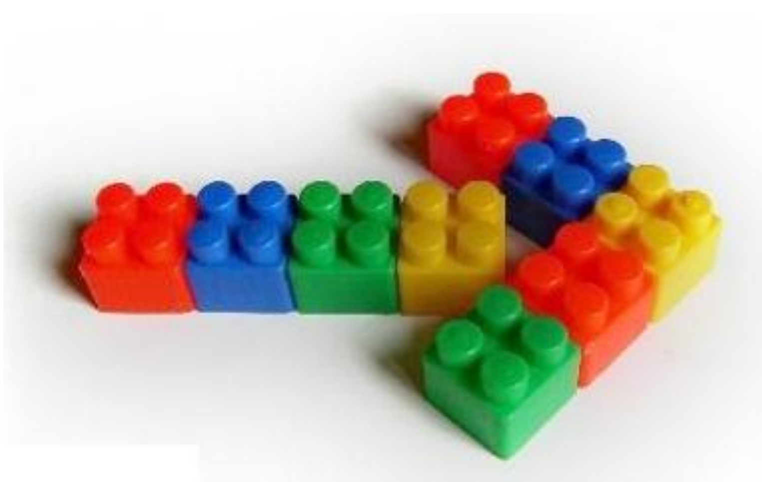

Figure 37 *Modularity only makes sense for certain products*

4) Modularity only makes sense for certain products.

The design team noted that although modularity offers several benefits, it does not make sense when applied to all electronics. Rather, it makes sense only for a subset. After some consideration, the team realized that modularity does not make sense for cheap products because it is more inexpensive and practical to simply replace the entire device, rather than a specific component. In addition, small products can be difficult to take apart easily and manipulate, so modularity does not make sense here either. A product that is too integrated (e.g. the product's components are all contained on the same PCB) cannot be made modular without a fundamental redesign, making it unlikely that the manufacturer would comply.

Modularity does make sense, however, for products where certain components break more frequently than others. In addition, if a portion of the technology within the device becomes obsolete quickly (such as the laser within a DVD player), modularity is very appealing.

A product class that satisfies the above requirements: POWER TOOLS

The team initially recognized power tools as a class of electronics that satisfied the above three requirements. After some basic research into power tools, the team decided to press ahead with this direction. After returning to their respective universities, both design teams began to conduct deeper needfinding and benchmarking studies (Appendix F).

Figure 38 *Disassembled power drill*

It began to emerge that power tools, although appealing as a product class that was generating significant amounts of e-waste and whose learning's could be extrapolated to other products, were already highly modular in their design. Figure 38 demonstrates the tightly compartmentalized structure of a drill that the Stanford team took apart.

After researching the products, users, and needs related to power tools, both teams agreed that there were other product categories that provided more room for innovation. This led to a temporary divergence, followed by a subsequent re-convergence, which resulted in the final winter prototype.

DIVERGENCE AND RECONVERGENCE

Upon deciding that power tools were not the best product class to approach, the teams decided to "diverge" and explore other product classes that were attractive. After brainstorming for a few days, the teams decided the laptops were the best product to address for the following reasons:

- Almost 200 million laptops are sold every year
- Laptops are common devices, and are immediately familiar to almost everyone
- Laptops share materials, high-tech (PCBs, batteries), and low-tech (fans) components with other electronic devices, making it easier to extrapolate insights.

In choosing laptops as a new direction, the team switched focus from extending the product lifetime to dealing with disassembly at the product's end-of-life (EOL). This switch was necessary because of the highly integrated nature of laptops – the number of separate components contained within the case does not usually exceed ten. Therefore, the team would not be able to make the components of a laptop modular without redesigning the electronics themselves. Focusing on EOL, however, presented many opportunities for innovation. The team decided to adopt a two-pronged approach:

[1] Design an EOL experience that increases the rate at which users properly recycle their laptop components.

[2] Use functional modularity as a method to distinguish the design team's product from other laptops in the marketplace.

4.3 Laptop Development

Having chosen a direction for the final product solution – laptops – the team began to focus in on what such a solution might look like and how its design might incorporate the team's critical insights about consumer behavior. The following chapter navigates the team's laptop design development, from an initial driving vision to component deep dives and, finally, to the end product solution.

4.3.1 Vision and Mission

The design team's vision is to substantially reduce the 50 million tons of electronic waste that are added to landfills every year by developing a broad class of fully recyclable electronic products characterized by quick disassembly and effortless separation and disposal of the components by the user at end-of-life. Additionally, the products will take advantage of functional modularity to distinguish themselves from competitors in the marketplace.

The design team's mission for the final product was largely guided by the results of needfinding and user-testing early prototypes. Three key pillars framed this mission:

1) The user will be able to disassemble the laptop easily, intuitively, and without the use of tools.

The disassembly process for the current generation of laptops requires that a user dedicate at least 30 minutes of their time to hack at the myriad of screws and fasteners that hold the product together. This process is extremely frustrating for users, and presents a significant barrier for user-side disassembly, which the design team has found to be a necessary for reducing recycling costs overall.

2) The laptop will achieve "greenness" as a by-product of its design.

User testing strongly demonstrated that users were not willing to purchase a product simply because it was more "green" than its competitors. Performance, durability, and cost were the primary factors that influenced the decision to purchase or not purchase. Therefore, if a "green" product is to see success in the commercial marketplace, its "greenness" must not be the main selling point, but instead, a by-product of its design. The main selling points must be other qualities that the user finds valuable.

3) The laptop will provide an engaging EOL disassembly experience that will remind the user of the product's lifecycle.

The user must have an incentive to disassemble the laptop at EOL. User testing showed that users are far less likely to respond to financial or physical rewards in return for disassembly. Instead, they responded more positively to a compelling and interesting experience that reinforced their "feel good" internal motivations to recycle. Reminding the user of their wider role in the product life cycle helps the user to understand the role they play, which provides encouragement to disassemble the laptop and dispose of the parts properly.

Goals for Remainder of Project

The design team sought to nail down a set of goals that would serve as stepping-stones toward fulfilling the product vision. These goals were purposefully high-level, and the team later broke these goals down further so that smaller, tangible steps could be taken.

1. The first important point that the design team needed to establish was a target user point of view (POV). This was crucial because the product needed to be tailored to suit the needs, preferences, and problems that were specific to the target user group. It was not only important to create a physical product whose features met the needs of the users, but having a target POV to address also helped the design team conceptualize the person (along with their habits and attributes) whom they were designing for.

2. The second overarching goal was to create a set of design requirements for the laptop that were specific to the POV. The design team had agreed early in the project's timeline that the most important outcome of their efforts would be this set of requirements. In the hands of a manufacturer, the physical specifications could be tweaked and optimized to fit particular laptop models, but as long as the requirements were followed (or improved), the laptop's materials could be disposed of safely and efficiently. The team had initially hoped to create a set of design requirements that could be extrapolated to make many different classes of electronics beyond laptops "greener", but it soon became apparent that this lofty goal was beyond the scope of the project.

3. The final goal was to produce a physical product that would embody the key requirements and goals set forth. The team did not expect to be able to produce a perfect final product, but wanted instead to be able to prove that a greener laptop could be built in such a way that it was desirable to average consumers within the POV. Using the design requirements, any manufacturer would then be able to apply these principles to their own products, thereby penetrating the market!

4.3.2 Establishing a User POV

Figure 39 *User Point of View is important to design*

The team considered several possible target user groups to design for. Each group had its own set of attributes that dictated how they would respond to the team's final product. These candidate groups emerged from the team's general needfinding and talking with users; as common patterns of needs and desires emerged, the following groups were discussed to compare and contrast their various qualities.

Potential Target User Groups and Their Needs

JAMES

Figure 40 *James: User POV #1*

For lack of a descriptive name, the team created a user group known simply as "James." James was a fantasy personality (created by the team) who represented the collective concerns, habits, and lifestyles of many of the users that were encountered while user-testing and needfinding. In particular, James demonstrated a concern for the environment, but did not have the time to comparison shop for the greenest purchase. He tended to choose products that were cheaper (functionality and durability being equal), but would upgrade his electronics every few years to stay relatively up-to-date. James had a family with young children, so safety was a high priority. The team crafted a story for James that helped us visualize him:

Meet James. James is 33, married to Lisa (29), and has a two-year old daughter, Susie. He is a marketing manager at P&G, works long hours during the week and rarely makes it home in time for dinner. He loves his family and makes every effort to spend time with them despite his crazy work schedule, especially on the weekends. The health and safety of his family is of utmost importance to James, so he has made sure that his home is both safe and free of toxins and hazardous materials. He tries to be eco-conscious but doesn't have time to dedicate to researching everything "green." For example, he knows that he should properly dispose of the pile of old electronics in his garage, but he just doesn't have the time to figure out what to do with or where to take them. James considers himself a tech user (he and his wife each have a laptop and smart phone) but is not familiar with how electronics work and thus relies on professionals to fix any tech problems he encounters.

GENERATION Y

Figure 41 *Generation Y moodboard - User POV #2*

The design team in Helsinki conducted an investigation of the characteristics of "Generation Y." These users were mostly born after 1980 were characterized by their familiarity and comfort with technology. The characteristics of this target user group are described below:

- Impatient, lazy, and easily bored
- Want constant feedback and immediate recognition
- Highly responsive to social motivations
- Highly image-conscious
- Seeks rationale behind requests

HACKERS

Hackers were a group of users who enjoyed taking products apart, fixing or modifying them, and putting them back together. Although this user group offered the team the chance to make interesting design choices, it was decided that they were not mainstream enough to design for. By catering to the rather niche group of hackers, the team would be sacrificing their ability to meet the needs of an average person.

Establishing a Final POV

In the end, the design team decided that because the product being designed was for a future scenario that would assume a basic recycling infrastructure, it made sense to make the up-and-coming Generation Y as our target user. Because laptops are such a ubiquitous electronic product, it was difficult for the design team to concentrate on only one particular user group. After all, every generation uses laptops to one degree or another. Although the laptop was designed primarily for Generation Y, the design team constantly thought about how their design decisions would affect other user groups. This would help extend the appeal of the product beyond just one target user, and could help the product enter the mainstream market.

4.3.3 Proof-of-Concept Prototypes

Introduction

The Stanford and Helsinki design teams each created proof-of-concept laptop prototypes in order to test their respective hypotheses about their areas of focus. The Stanford team concentrated on easy disassembly mechanisms and the EOL experience (a seedbox), while the Helsinki team focused on incorporating functional modularity (a removable keyboard) and a no-tools method for opening the case. These proof-of-concept prototypes provided valuable feedback for the design team.

Easy Disassembly and EOL Experience (Stanford Prototype)

As described in the vision, the design team sought not only to create an easily disassemblable laptop, but also to craft an experience for the user surrounding the EOL process. In pursuit of this goal, the Stanford design team created a laptop prototype that delivered valuable feedback on some of the team's hypotheses.

EASY DISASSEMBLY

Easy Disassembly - Mechanisms

A proof-of-concept (POC) laptop was designed and manufactured to test the team's theories about what constitutes easy disassembly. A picture of this laptop can be seen below in Figure 42. The laptop was made out of sheets of acrylic that were cut with a LaserCAMM and then stuck together using acrylic glue. The laptop hinge was simply a door hinge with one side attached to the bottom of the case, while the other side was attached to the screen case.

Figure 42 *Functional proof-of-concept laptop prototype*

The laptop was not intended to be functional – in place of a keyboard and mousepad, only black acrylic painted with a faux keyboard and mousepad was presented. The decision to not create a functional laptop was made because the team sought to concentrate on the *end-of-life* disassembly mechanisms, and therefore, it was assumed that the laptop would not be functional at this point.

It was thought that the natural point (from the user's point of view) for beginning the disassembly process would be flipping the laptop over and opening the bottom of the case. Users we had spoken with had already indicated that they were quite used to flipping the laptop over in order to change the battery, hard drive, or RAM. Figure 43 shows what a user would see before starting to disassemble the laptop. Note the safety warning that all power sources should be disconnected before proceeding.

Figure 43 *Opening the underside of laptop prototype*

Upon opening the underside of the laptop, the user would be presented with all of the hardware, in addition to a set of visual instructions that guides the user through the full disassembly process. These instructions are removable, so that the user can take them out and set them aside when the laptop needs to be flipped to access the screen. Figure 44 shows the visual instructions.

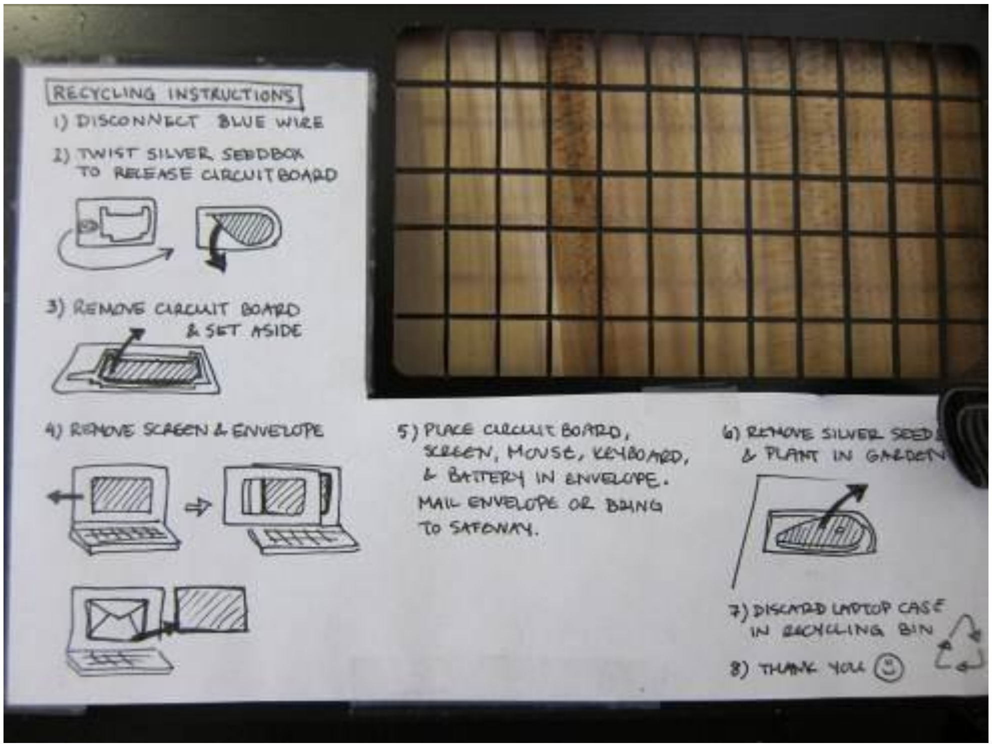

Figure 44 *Disassembly instructions*

By following the disassembly instructions, the user would be able to completely separate the hardware from the case materials. This POC laptop was then subjected to user testing in order to determine which disassembly mechanisms users found intuitive or easy, and which they found to be confusing.

Easy Disassembly – User Testing

The user-testing was conducted at Tressider Union (on the Stanford University campus) and at a local coffee shop. The results of the user-testing were mixed. Some of the disassembly instructions were completed by most users without a second thought, while others would present a stumbling block.

Removable instructions were certainly a must-have, as users displayed significantly more frustration when they had to flip the laptop over but were forced to leave the instructions stuck to the underside of the case. Removing the motherboard presented no challenge to most users, validating the team's hypothesis that simply displaying the "guts" of the computer at EOL made it easier for the user to remove them. The screen disassembly process (shown in Figure 45) also seemed quite intuitive to users, primarily because of the sliding arrow indicators painted on the screen case.

Figure 45 *Sliding screen apart*

There were, however, aspects of the disassembly process that were not easy for consumers to understand. Disconnecting the cords between PCB's proved to be a significant hurdle for users, and they frequently tugged on the incorrect end of the correct cord, or would pull on the wrong cord altogether. The way in which certain wires or small components were distinguished from their surrounding was not clear enough. Pulling on the wrong end of the cord would not normally be a problem at EOL (since the device is already assumed to be non-functional), but for the purposes of repair or upgradability, disconnecting a cord incorrectly could damage the computer hardware. The team noted this flaw in the disassembly process and sought to improve upon it in later prototypes.

EOL Experience and Incentives - Seedbox

The team recognized that the motivation to disassemble the laptop must be very compelling to the user. The laptop design strove to accomplish three primary goals:

1) offer a compelling incentive to begin disassembly of the device,

2) harness the internal eco-conscious motivations of users to disassemble the device while coaching them through the disassembly and recycling process, and

3) offer a simple way to recycle all components (including NCR components) from the home.

Finally, as in all of the prototypes, the team strove to offer the user an experience surrounding the act of recycling – engaging the user in the process itself.

To accomplish these goals, the design team settled on the concept of a laptop "seedbox" similar to that discussed in the Fall Quarter CFP section. The seedbox was a biodegradable plastic component of the laptop that contained a seed inside that could be planted in a garden. In the Stanford prototype the seedbox played a critical role inside the laptop; it was connected to a set of gears and held the motherboard in place within the laptop case. The team believed that the seedbox itself must be a critical component of the device in order to elicit the feeling that a part of the laptop itself had been planted (avoiding the notion that there was simply a bag of seeds inside a plastic case). Previous versions of the seedbox had involved running wires through the biodegradable material that would permanently disable the laptop, but this idea was scrapped due to logistical, ecological, and repair issues. The team believed this to be a compelling reason for the user to open the laptop case, as previous user testing had indicated that the pairing of an organic life form and digital hardware presented an intriguing and curious scenario to the user. It also served to closely link electronics at EOL with the notion of the environment, thereby tapping into the user's internal motivations to recycle.

The seedbox is an integral, functional component of the laptop design because it serves as the latch for holding the PCB in place within the case. What makes the seedbox particularly compelling component is the fact that it can be removed from the laptop at the device's end of life and planted in the ground, thus creating a unique, engaging end of life experience for the user.

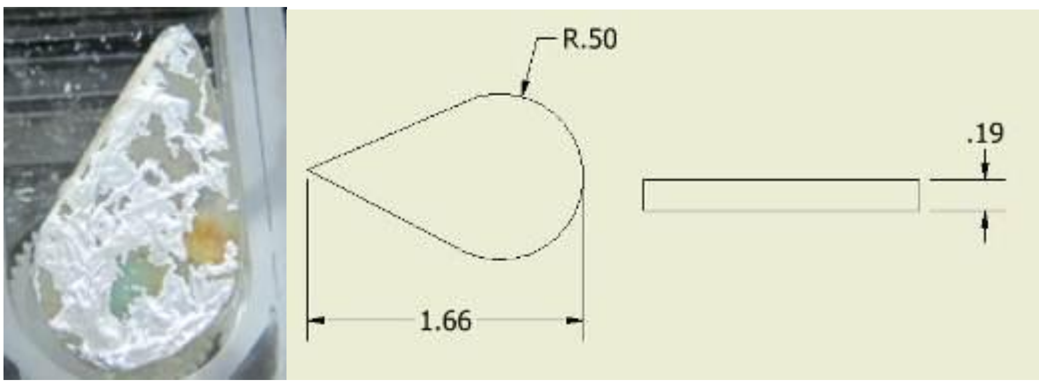

Figure 46 *Seedbox dimensions*

MATERIAL

The seedbox was made from biodegradable plastic molded into the shape of a teardrop (Figure 46). For the Functional System Prototype, the team constructed the seedbox from NatureWorks PLA because it was the most readily available biodegradable plastic. However, since the seedbox will be an internal component of the laptop for at least five years, it needed to be able to endure constant changes in temperature, humidity, and applied forces (including vibrations) – in the real world, PLA would not survive these conditions. Therefore, in possible future iterations of the seedbox, the team would recommend using Mirel P1003 injection molding grade plastic because of its high performance characteristics. Mirel P1003 heat distortion temperature is approximately 172-290 degrees Fahrenheit (depending on pressure), which is more than durable enough to withstand the heat of a microprocessor, which can reach 160 degrees Fahrenheit. For a table describing the full material properties of Mirel P1003, see Appendix F. Mirel P1003 is also a good material candidate for the seedbox because it is biodegradable in soil and marine environments and will compost in home composting systems.

SEED

Inserted in the middle of the seedbox is a Bird Vetch seed – when the seedbox is planted in the ground and biodegrades, the seed will germinate and grow into a purple flower. The team chose to user Bird Vetch because (1) it will last a long time in a vacuum-like environment without germinating, (2) it is very tolerant of temperature differences (which it will experience within the laptop), and (3) it requires little water to grow, which means that the user will not have to water the seed very often.

PROTOTYPE CONSTRUCTION

To create the seedbox, the team built a small teardrop-shaped mold from aluminum foil and filled it with shredded PLA. The filled mold was placed in an over at 350 degrees Fahrenheit for 10 minutes so that the shredded plastic melts and takes the form of the mold. Immediately after taking the mold from the over, a small seed is pressed into the melted plastic. The mold is then returned to the oven for one minute to melt the top layer of plastic and fully encase the seed within the plastic. Once the seedbox cools, the aluminum foil mold can be removed.

USER TESTING

The seedbox was cautiously received by users who disassembled the laptop. It was not as compelling of an experience as the team had initially hoped, but the users found it to be an interesting curiosity. They were intrigued by the idea that a lifeform was contained within the laptop, but indicated that it was not a strong enough incentive for them to disassemble the laptop if they encountered such a laptop in the real world. The team decided to abandon the seedbox incentive, having seen a lukewarm reception from the users.

Modularity

A second proof-of-concept prototype was constructed to test the team's design for functional modularity and no-tools opening mechanisms of the casing. In the previous prototypes the team identified that the three main tenets of the modularity approach are: ease of upgrade, ease of repair, and possibility for personalization.

By making a product modular in design, only one particular portion of the system may need to be upgraded at any given time. In addition, the team wanted to test the users' perceptions on the benefits of functional modularity. With functional modularity the team imagined a single physical device capable of performing multiple functions through simple exchange of parts.

The modular feature to be tested was the keyboard, which the team designed to be removed from the casing and used wirelessly. In addition, the team designed a no-tools disassembly method for the casing. By designing a modular, yet green product, the team assumed that the added value to the product would require no sacrifice of quality or performance and would provide new benefits for the user, as well as a greener computer.

PROTO #1: DESIGN DESCRIPTION & USER EXPERIENCE

The Helsinki team built two prototypes. The first one was a proof-of-concept laptop with a keyboard and a trackpad that can be easily removed (although the keyboard and mouse are still connected by wires) (Figure 47). The team intended to use the first prototype as a communication tool to gain more mechanical and electronic knowledge about laptops. The team visited Helsinki HackLab and asked the people there to experience the first prototype. The team asked questions concerning the modularity of the product and revealed the environmental aspect only in the end. The Hackers' expertise taught the team a lot about the construction of the laptop and introduced new viewpoints and benchmarks (Table 9).

Figure 47 *Using the modular track pad in a new way*

Figure 48 *"Hackers" playing with the modular keyboard*

Besides the rigid construction requirements, the Hackers also offered some suggestions for designing a modular laptop.

Feedback from hackers

- **Solidness**: "It wasn't quite right, it wasn't as tight as you'd want it to be" – the product must feel 'solid' during use.
- **Disassembly**: Keeping track of different parts is important. Feedback is necessary (visual, tactile, sound).
- **Design**: "The problem is that products are made too ready. When you are done with it, it is thrown away" – designing for disassembly requires that the user understands its modularity
- **Security**: The user shouldn't be able to remove the hard drive while the computer is on.

PROTO #2: **PROTO #1 REVAMPED**

Based on the combined knowledge and expanding ideas, the team built the second prototype of much higher resolution that focused on the wireless keyboard. The team bought the smallest possible keyboard with an embedded trackball in it to serve as both keyboard and mouse for the prototype. The keyboard dictated the dimensions for the design. The first version of the casing was designed to be 3D printed. However, due to time constraints 3D printing was abandoned and the case was milled instead.

The team decided to include the ergonomics as a "wow-effect" since it is one of the benefits of modularity and would made mobile working easier. It also communicated the idea of modularity in an easy to grasp form. By observing the laptop users, the team found out that posture, keyboard spacing, screen size and positioning, and pointing devices usually take the biggest ergonomic pain point (Figure 49 and Figure 50). Even though laptops are designed for portability, many people use them as a desktop computer.

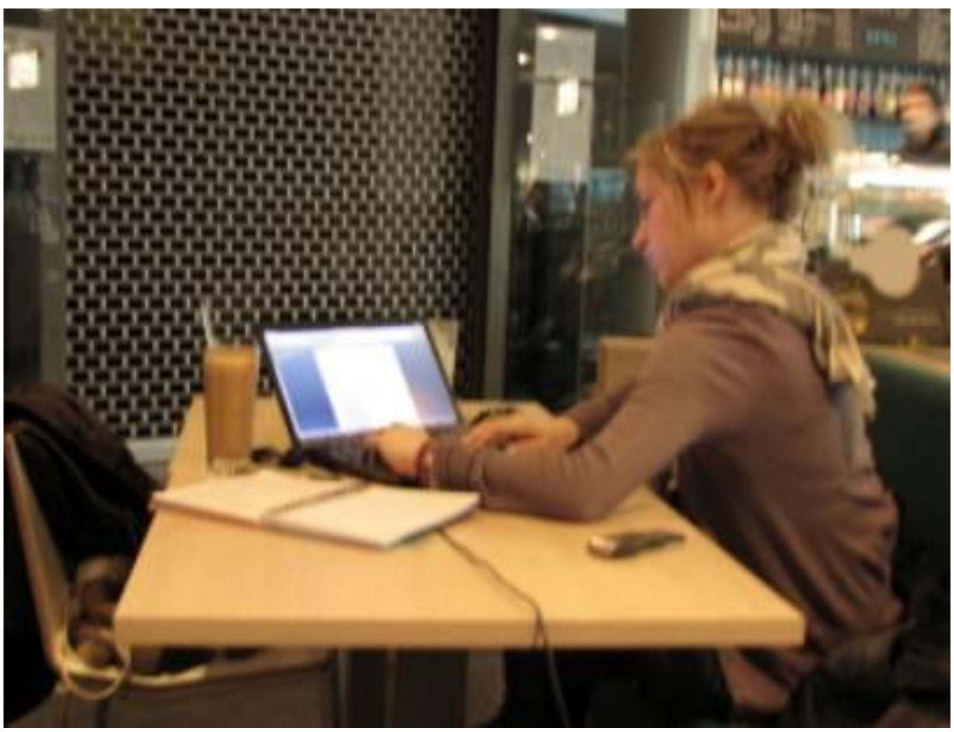

Figure 49 *Unergomonic positions when using laptop in coffee house*

Figure 50 *Keyboard is not wide enough, resulting in write strain*

Problem	Symptom	Cure
Keyboard spacing - laptop keyboards are often compact with odd placement of some keys and cramped spacing of others.	Preventing wrist repetitive stress injuries	Keep the wrists in the most natural wrist position that you can achieve.
Small pointers - laptops usually have an integrated pointing device such as a touch pad or dot. These devices are adequate for there task, but not very comfortable or easy to use for long periods of time	Preventing wrist repetitive stress injuries	
Monitor size - laptop screens are often smaller than desktop monitors.	Preventing eye strain	Make the laptop setup as close to the desktop ergonomic computer station setup as possible.
Monitor placement - the relation of the keyboard to monitor on a laptop is fixed. A proper ergonomic monitor setup has the monitor and keyboard at different levels and spaced far apart	Preventing bad posture with either arms and hands held high or the neck and back bent low.	Rotate the screen so that bending of the neck is minimized. Tuck the chin in to rotate the head instead of bending the neck. Elevate the rear of the laptop so that the keyboard is inclined.

Table 9 *Main ergonomic issues with laptops*

USER TESTS

The second prototype aimed at finding out how users evaluate the benefits of modularity and whether people would want to use amodular product at all. The team chose to study users of the Generation Y group. The team visited a youth club, observed and interviewed around ten 14-16 year olds, and obtained the basic knowledge of what they like and dislike, what their values are, what their attitudes towards the modular laptop are, and in what scenarios they might use the laptop. The teenagers were also asked to make imaginary laptops out of play-doh and play with the modular laptop prototype. The notes from the user study can be found in Appendix F. The team analyzed the qualitative data and observational anecdotes for drafting the table of Generation Y characteristics and the implications for the design. Meanwhile, the specific benefits might rise from modularity for generation Y were mapped out.

Figure 51 *User testing in a youth house in Tapiola*

Generation Y characteristics and the implications for the design:

Impatient and lazy. Easily bored (less consumerism, more engagement and stimulation).
Introducing an engaging disassembly process. Design something quick, motivating and understandable in max. 7 seconds. They use laptops non-conventionally, on the bed, in the floor, but not that much outside the home.

Want to be nurtured (constant feedback, immediate recognition)
Feedback system for the disassembly/repair. Comes with a map of all the components and full instructions for the removal of the all the parts.

Unresponsive to motivational tactics. Motivated not only by money, but also fun and social. Image conscious and materialistic. Eco-conscious, but only as a by-product, mostly they are interested in entertaining themselves or each other
Creating personal relevance for the disassembly. Implementing gaming mechanisms in the process. Making modularity a question of personalization.

Demand rationale behind any request
Communicating the sustainability and e-waste problem in an efficient manner.

From this prototype the team was able to map out the different benefits that might arise from modularity.

BENEFITS OF MODULARITY		
	Benefit	**Explanation**
User benefit	Ergonomics	Young people aren't yet concerned with ergonomics, but they eventually will be.
	Repairability and cost savings	If something goes wrong you don't have to replace the whole thing, or send it back lock stock and barrel to the manufacturer and wait impatiently for its return; you just replace the individual component. The easiest things shouldn't be repaired by the most expensive people. Different components become outdated a t a different pace. Processor etc. grow old quick, screen not that often.
	Custom modifications	Product can be designed to have many options that the customer can choose from. A base unit, which would only need to be designed once, could accommodate any number of device options. Each option can then be designed independently.
	Deeper understanding of the product.	The laptop is designed to be *approachable* by any user - it is no longer a high-tech mystery. The user understands what the primary components are and what their purpose is. They gain this knowledge from some sort of initial exposure to the guts of the laptop and then can quickly become familiar with the components because they are clearly labeled, modular, and require no tools to remove/replace.
Strategic benefit	Possibility for Differentiation	Providing more benefits to customers through product functionality, flexibility and modularity, providing additional services and focusing on selling the functional needs that customers actually want. This raises the possibility of the customer receiving the same functional need with fewer materials and less resources.
Business benefit	Lean manufacturing.	Lower readiness costs. Less assembly.
	Profit potential	Because the entire laptop doesn't have to be created as a solid unit, and because each part can be directly sold to the public (rather than via distribution channels to other manufacturers as many of component makers do today), that means larger profit potentials for many companies, and lower costs for consumers.
	Ancillary sales opportunities	Use the Momentus drive to create opportunities to deploy high performance, higher margin systems. Also some possibilities for a premium price.

Figure 52 *Benefits of modularity*

The potential design opportunities that arise from the user test results and insight include:

Design Opportunities

- Swapping out a circuit board (similar to memory cards)
- Placing more functionality in parts that can be easily replaced like controllers & remotes
- Designing for aesthetic/functional switching through more attachment inputs
- Making upgrading a 3 mega-pixel camera to an 8 mega-pixel as easy as switching lenses
- Teaching the users the solution: what good is a magic button to release all connectors (screws, snap fits, etc.) if you don't know that it exists on the unit and/or where it is located?
- Implementing different kind of instructions to the laptop: e.g product information for inventory and sorting purposes, identification, location and removal instructions of components containing hazardous substances and identification of plastic resins for separation for processing of plastic resins for separation for processing users.

Conclusions from Proof-of-Concept Prototypes

The design team learned valuable lessons from the Stanford and Helsinki proof-of-concept laptops. The main takeaways were:

Key lessons learned

- Uncluttered, removable visual instructions are absolutely necessary to guide the user through the disassembly process.
- The laptop should be designed so that it can be completely disassembled without needing to flip or reorient it once it has been opened.
- The seedbox was a curiosity to the users, but was not so compelling that it significantly increased the chances of disassembly occurring
- Pull-tabs must be clearly marked on all wires and interconnects, so that the user knows which cord to disconnect and from which end
- Consumers within the target user group were highly in favor of being able to remove the keyboard/mousepad from their laptop and use it wirelessly

4.3.4 Component Deep Dive

Introduction

The proof-of-concept gave the design team a strong idea of what the final solution would look like on a medium level. For the next phase in the design development, the team wanted to focus on the design detail, and therefore sought to produce a high-resolution final prototype of one specific portion of the laptop. This necessitated that the two major physical portions of the laptop, the screen and the base, be designed in a way that would give the product the look and feel of a real laptop. The Stanford team members concentrated on finalizing the design of the laptop's friction hinge, while the Helsinki team members investigated ways that the base of the laptop could be opened without needing to reorient the laptop.

Screen and Hinge

The team attempted to create a friction hinge for the laptop that would function just as reliably as a hinge in any other laptop, but that could be easily disassembled by the consumer at EOL. As a brief reminder for the reader, a laptop's friction hinge is the mechanism that keeps the screen from falling backwards when the laptop is opened. It maintains the desired screen angle for the user, and is a crucial component of the laptop. Unfortunately, friction hinges found in the current generation of laptops are neither made out of recyclable materials, nor are assembled in a way that is easy to take apart. An extra complication that had to be considered when designing this hinge was that the screen cord had to be somehow threaded through the hinge so that it could be connected to the motherboard.

The team progressed through several quick prototypes to test their ideas for the friction hinge. The first prototype is shown in Figure 53. The screen and base sections of the laptop were modeled by sections of fiberboard, while the hinge itself was made out of sections of PVC pipe. The circular edges of the pipe were scored with a razor, and then pushed together by screws on either side of the laptop. Friction was generated as the pipes attached to the base fiberboard rubbed against the pipes that were attached to the screen fiberboard. This prototyped demonstrated to the team that such a method of generating friction was feasible.

Figure 53 *First rapid prototype of laptop hinge*

The team then created another rapid prototype in order to test if the screen cord could be slipped through the friction hinge and into the base. This prototype can be seen in Figure 54. After constructing the prototype, it was clear to the team that such a method did indeed work. It became clear, however, that the central rod that can be seen running through the outer pipe in Figure 54 would complicate the design. If a screen cord were threaded through a central rod within the friction hinge, it could become entangled or even snap.

Figure 54 *Second rapid prototype of laptop friction hinge*

After the construction and testing of these two prototypes, the team realized that although squeezing the parts of the hinge together was a good way to generate friction, it was not possible to run a central rod through the hinge. The team decided, therefore, to tweak the design so that the friction would only be generated on the two outer edges of the laptop, while the central section of the hinge would be hollow to allow the screen cord to pass through (this final design is described in the more detail later).

Key lessons learned

- The screen cord should not pass through a section of the friction hinge that twists in order to prevent damage to the cord
- Friction generated via the method described above (pressing pieces of the hinge tightly together) can slowly reduce over time as the laptop is opened and closed repeatedly
- The hinge should be made of one material if possible, so that it can be recycled along with the case

4.3.5 Nailing Down the Hardware

Introduction

The design team had to use hardware from existing laptops in order to create a final product; it was simply impossible to redesign laptop electronics from scratch. Because the hardware in each laptop is different in functional capabilities and physical dimensions, the final hardware had to be nailed down before the final laptop could be designed. This section describes some of the factors that went into the choice of hardware.

Factors Considered

Choosing the laptop with the correct hardware for the team's needs presented a challenge because it was difficult to know what the physical dimensions of the hardware were before opening the laptop. An important factor in choosing the hardware was its physical dimensions – especially its thickness. One of the team's guiding principles was to design a laptop that people could actually see themselves buying, and few would be willing to purchase a very thick laptop. It was necessary, therefore, to choose a laptop with a thin motherboard, hard drive, and other internal components.

In addition, the hardware needed to be interconnected by cables that could easily be extended. The design team knew that they would be changing the orientation of components within the case, and therefore, certain wires would have to be extended using a soldering iron. The wires interconnecting PCB's had to be large enough that we could solder them.

Recyclability of the hardware did not play a large role in the choice of hardware for two reasons:

1. It was impossible to determine how recyclable a PCB was from looking at it.
2. All PCB's required special handling by the recycler, so it was unnecessary to find especially "green" hardware.

Choosing the Final Hardware

Figure 55 *2009 MacBook*

After exploring the hardware various laptops (from HP, Dell, and other PC makers), the design team finally settled on the hardware inside the 2009 MacBook. This hardware had the advantage of being the thinnest encountered. In addition, the components were highly integrated, thus reducing the number of parts that the user had to handle in the disassembly process. The wires between internal components were thin and flexible, but just large enough to be soldered by the team. This gave the team flexibility in how to orient the hardware within the case, thus providing more design options.

4.3.6 Final Design

Introduction

After the team had chosen the final hardware and created some proof-of-concept laptop prototypes, the time had come to freeze the design and begin creating the final product. Two iterations of the final product were produced for EXPE. The second iteration had slight modifications to the CAD files in an effort to improve the parts over the first iteration (described in the next subsection). This section will describe the final design choices that were made and the factors that influenced the decisions.

Prototyping/CAD

Final first iteration prototype

Before CAD modeling the case itself all of the laptop hardware was CAD modeled after precise measuring with calipers. Armed with the digital models of the laptop hardware the case modeling was undertaken. The opening mechanism was planned such that certain locations within the laptop case required extra room vacant of hardware, specifically between the battery and the circuit board.

The base was modeled to be as small as the existing parts allowed. Posts were modeled under the circuit board to hold it in place when the hatches would be closed – and this method was then extrapolated to all other circuitry. Almost all of the circuitboards were designed to sit snugly on posts within the laptop case.

The process for the screen case design was similar to that of the bottom case – first the components were modeled and then the case itself to hold those components. The overall depth of the screen was accounted for first and then the two halves of the screen were parametrically linked to always hold the screen tightly despite any changes to their overall shape. Depression areas for the press fit post guides were also parametrically linked to other part files to allow for easy re-arrangement of the configurations. A final design was chosen after running several Inventor tests for component part interference.

The depth and width of the removable keyboard were adopted from the bottom case and the height was dictated by the thickest keyboard components. These thick portions were primarily the battery and wireless transmitter. The placement of the keys and the trackpad was based on typical computer layouts and optimized for ergonomics. This resulted in a centered, high placement of the keys and trackpad in order to leave room for wrists to rest on the case. The opening mechanism for the keyboard was identical to that of the screen case.

Final second iteration prototype

For the final second iteration prototype, the design team added walls to the bottom case around certain components (such as the battery and charging PCB) to prevent them from moving sideways. The team also moved the charging PCB closer to the connector on the motherboard to avoid having wires spanning the base. Additional ventilation holes were also added to help disperse the heat generated by the laptop.

The speaker cases were completely redone to make the sound quality better and to make them fit better inside the bottom case. To improve the sound quality, there were also holes made in the back hatch above the speakers. In the front hatch, braces were added for additional reinforcement (to make it less flexible).

The keyboard case had many changes relative to the first iteration. The keys were moved down and forward to allow the laptop screen to close. Side support walls were added for every component to prevent sideways movement. In addition, a connection button was added on the right hand side of the top keyboard case.

For the screen casing, the team added grooves for all the wiring, while changing the width of the LCD screen depression to make it fit snugger. Holes for the webcam were also added and made the webcam fit more tightly in place.

Manufacturing Parts

The design team had initially desired to create the final laptop case out of aluminum. After receiving several quotes from vendors, however, it quickly became apparent that this would be impossible due to budgetary constraints and a long turn around time.

Instead, the team decided to fabricate the laptop parts using stereolithography (SLA), a 3D-printing process. The process itself, depending on the specific vendor, usually has tolerances in the few thousands of inches and is capable of printing a wide variety of plastics. The vendor used by the team, Prototypes Plus in Menlo Park, California, had a SLA machine with a very large printing bed, thereby removing a potential constraint. SLA presented an inexpensive and fast way to produce the laptop parts, so the team decided to pursue printing as the method of choice. The broad range of available plastics allowed the team to choose the appropriate polymer (ABS) such that the thinnest laptop could be made.

The first iteration of the final product parts can be seen in Figure 56. These parts were sand-blasted by the vendor, but were not finished. This was important because some parts had to be manually sanded or cut in order to get the pieces to fit together perfectly. If the parts were finished prior to the team's receiving them, the subsequent sanding would probably make the parts look shabby. All portions of the design that needed tweaking were then adjusted in the CAD files, so that a second iteration could be produced.

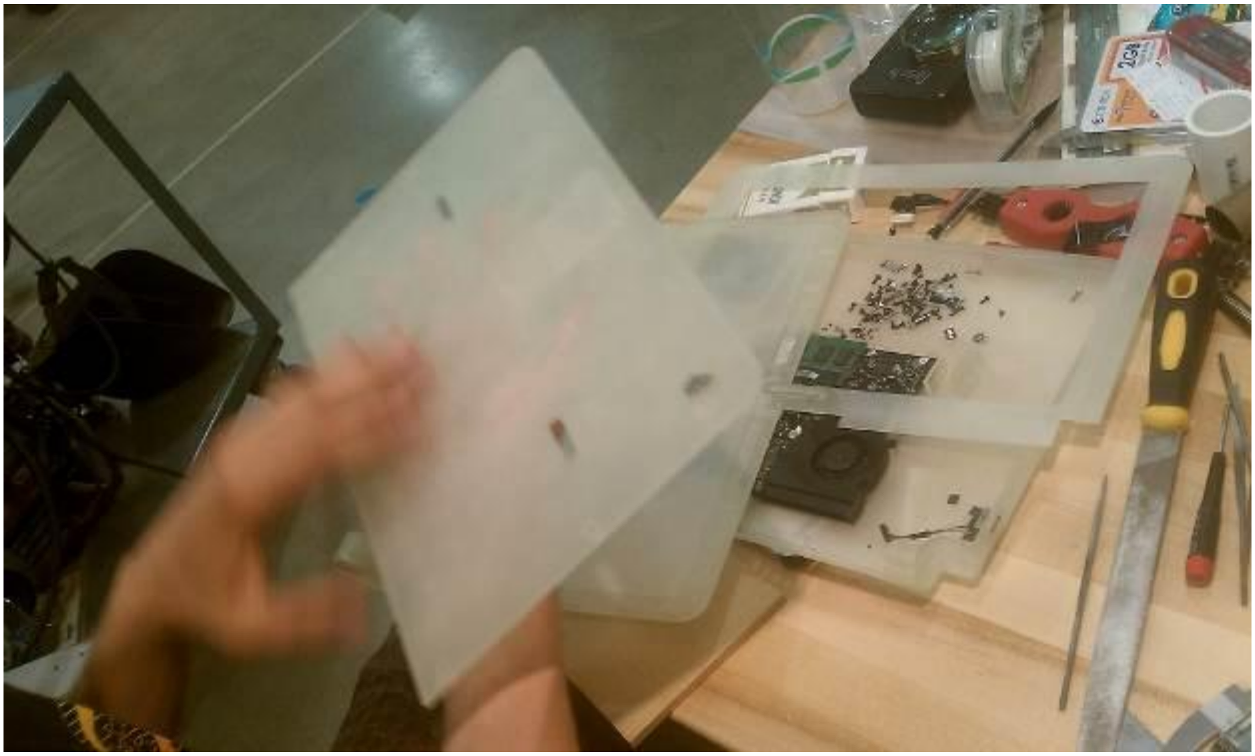

Figure 56 *3D printed parts from first iteration of final product*

The second iteration of the final product parts was ordered from the same vendor. These parts can be seen in Figure 57. Once again, these parts were sand-blasted but not finished. The parts had to again be manually sanded and cut due to small deviations in the printed parts from the CAD files.

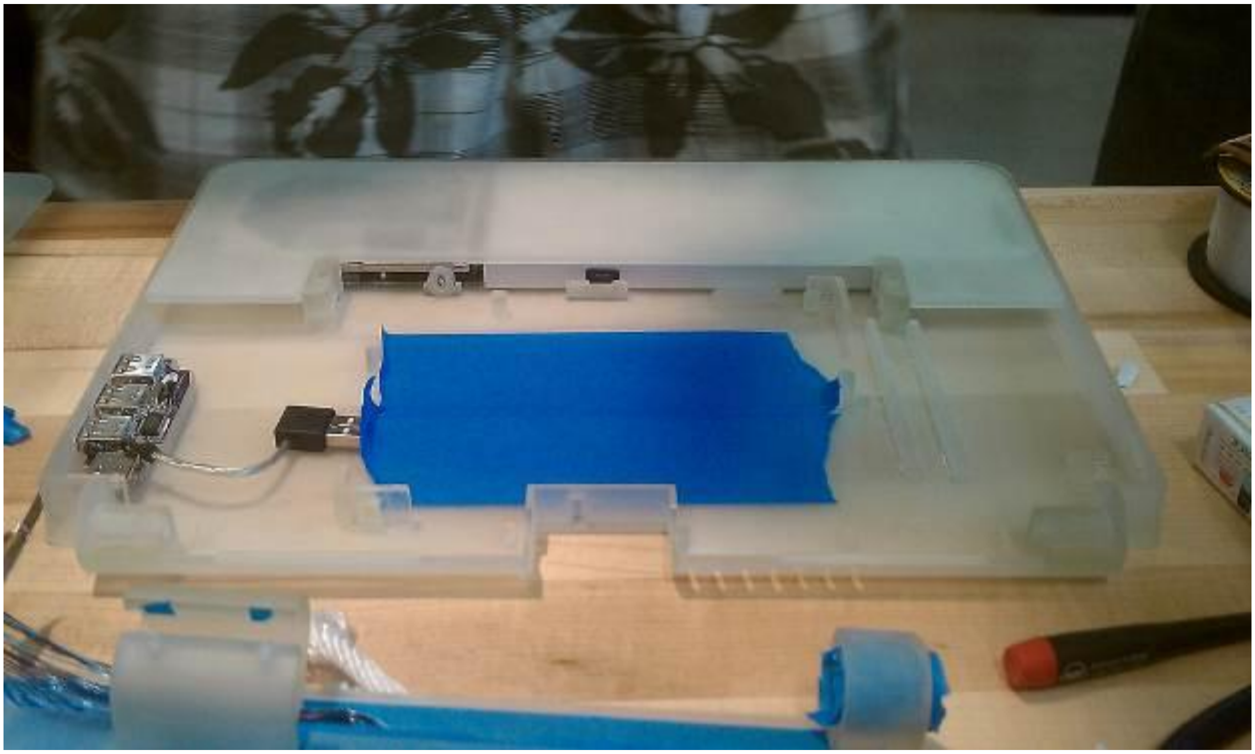

Figure 57 *3D printed parts from second iteration of final product*

The cost of the first iteration parts was $2,025.00, while the cost of the second iteration parts was $3,100.00. The difference in cost was due to the team deciding that redundant parts should be produced in the second iteration in case of any mishaps prior to EXPE.

Integration

Once the parts for the first iteration were received, the team began to tweak them so that they could be integrated with the hardware. Many small adjustments were made with files and razors so that pieces would fit together as they were supposed to. The process described below was the same for the second iteration, except where specified.

First, the modified hardware was placed into the base, as seen in Figure 58.

Figure 58 *Modified hardware in laptop base*

Then, the LCD screen was sandwiched between the front and back sides of the screen casing as seen in Figure RRR. This screen was then placed against the laptop base, and the aluminum hinges were inserted into place (Figure 59). The necessary nuts and washers were also screwed on to complete the friction hinge.

Figure 59 *LCD screen inserted between laptop screen parts*

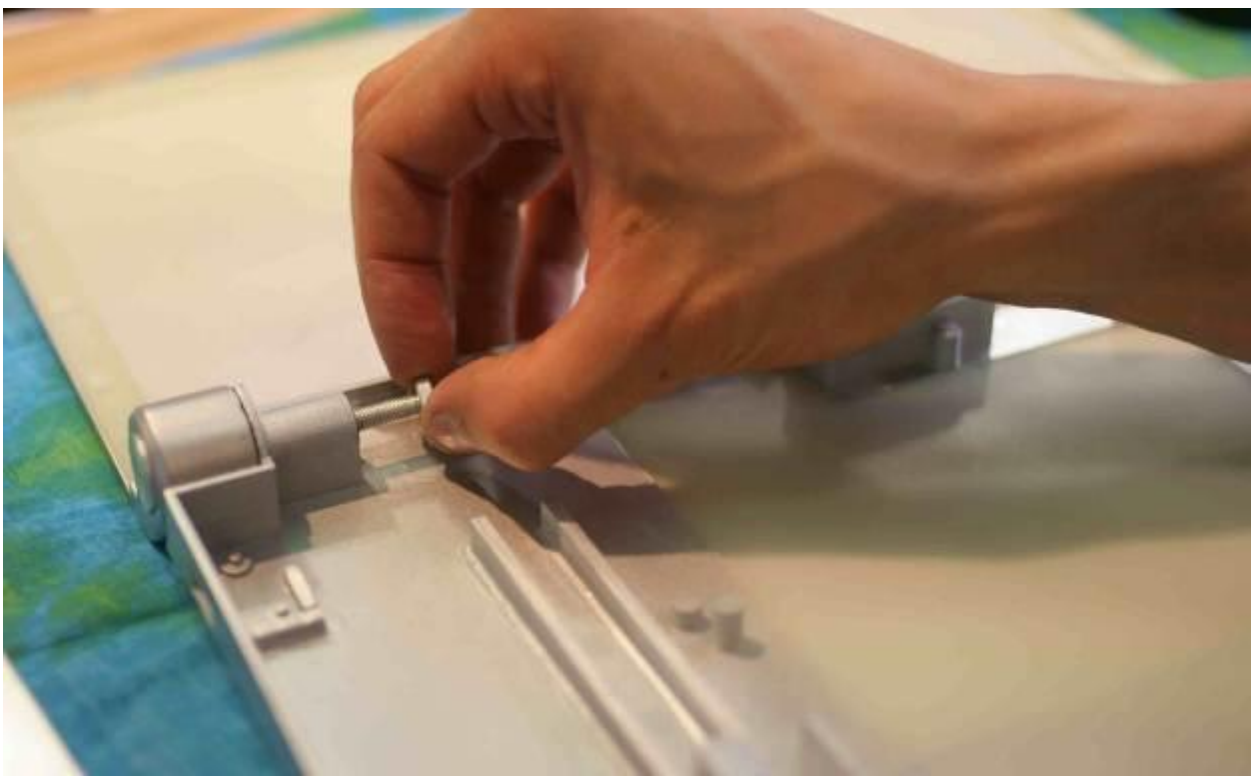

Figure 60 *Hinge axle being put into place*

The screen cord, which was threaded from the screen into the base, was then plugged into the motherboard. The back and front hatches were then put into place (Figure 61) and secured by twisting the bayonets (Figure 62).

Figure 61 *Back hatch being put into place*

Figure 62 *Twisting the bayonets to securely lock the hatches in place*

To create the removable keyboard, the back of the keyboard was first held in place. Then, the modified electronics were laid out on the back of the keyboard. The top of the keyboard case was then placed over the electronics, and locked into place by sliding the top case forward (Figure 63).

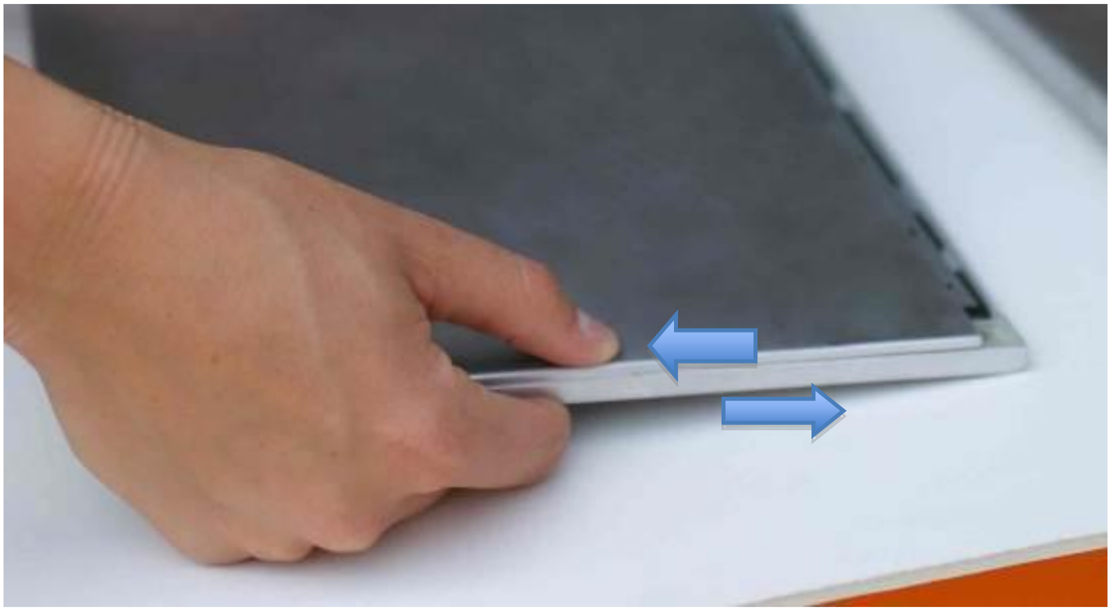

Figure 63 *Sliding keyboard case shut*

The first iteration of the final laptop was spray painted with an aluminum paint in order to give it a sleek look. The second iteration of the final laptop remained with the original finish to give it a "futuristic" or "alternative" look (Figure 64).

Figure 64 *Fully assembled laptop (aluminum painted)*

Instructions/Labeling

The team established early on in the design process that graphical disassembly instructions were necessary to facilitate consumer-driven product disassembly. Since the team had chosen a final product direction for the product, it was finally time to start designing these instructions and component labeling specific to laptops.

During the year the team had many ideas for the easy disassembly methods and identification of the parts. Color-coding came up several times as a way to identify components, as did numbers, symbols and names. After some brainstorming and user testing, the team resolved that there are at least four different things that component labeling and disassembly instructions need to communicate to consumers:

- The place where the component is situated
- The disassembly method and order of the parts
- The material the different parts are made out of -> recycling method
- The name/function of the different components.

In order to test the color-coding method, the team built a paper prototype of the laptop, on which was outlined the different components in different colors. Laptop "components" were out of cardboard and placed on top of the outlines. The outlines of both the component outlines in the casing and the components were colored with the same color. Connectors and wires were also made out of paper and tape. The component bed and components were embedded in the laptop casing.

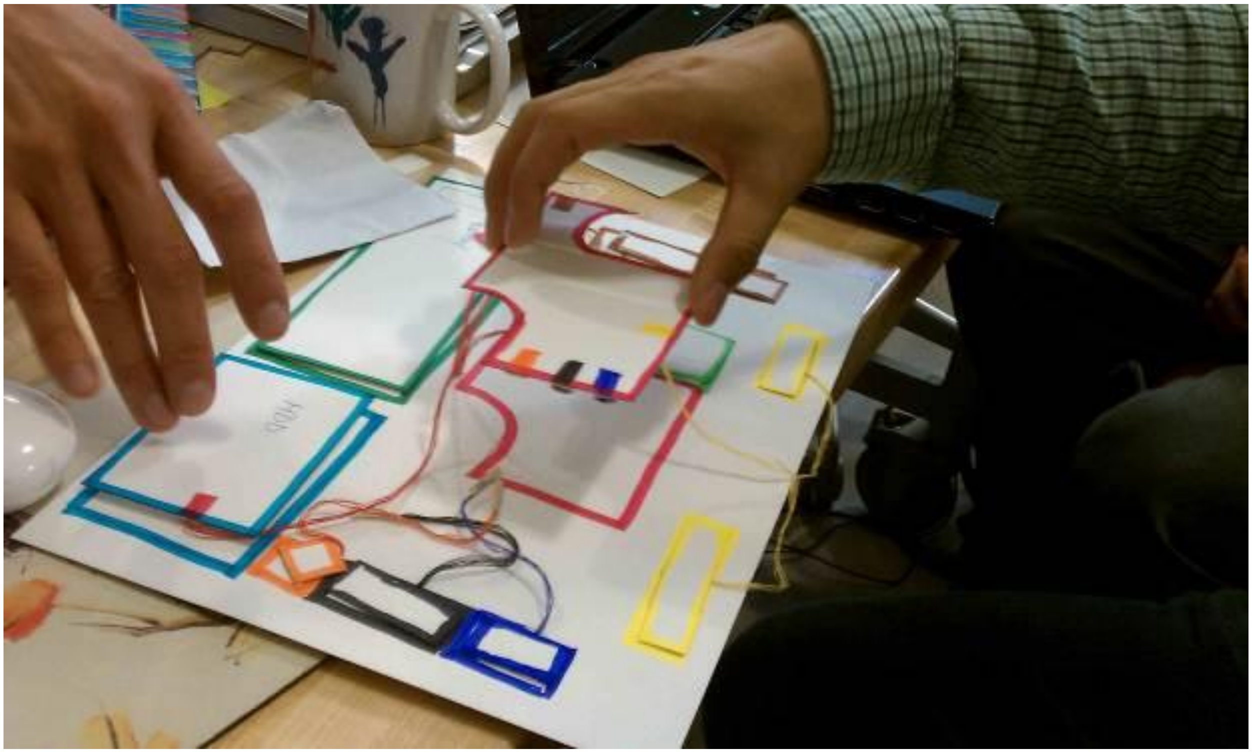

Figure 65 *Paper laptop with color-coded labels*

The team tested the instructions with two people. The user-testing plan comprised of three different parts:

3. Tested the sliding mechanism by making different sliding symbol stickers on the side of the screen. Users were asked to replace the screen without guiding them how to do it.
4. The second user testing focused on the hatch opening mechanism. Users were asked to first open the case to see whether they could find the hatch and if they could figure out how to open it.
5. The third testing was about color-coding, where users were given the task of replacing different components (with color-codes as guides). The team was particularly interested in how users loosened the connectors during disassembly.

Figure 66 *User tests for color-coding*

Key lessons learned

- Color-coding did not work quite as planned. The users did not even notice that the wires were supposed to connect to the same color component. Some of symbols should be represented as gestures so that it's easy to understand how the component is removed, not only in which order.
- Users also removed the components without loosening the connectors first. Also, the different kind of connection types misguided the users, especially the battery and HDD.
- All users forgot to disassemble the keyboard and track pad because they did not know there were components under the keyboard and track pad. Also, some users it still felt it was unsafe to disassemble the product without first removing the battery.

Design opportunities

- The hatch opening mechanism can be improved by changing the shape of the knob and by adding an arrow symbol.
- There should be a slot between the first hatch and the second hatch, to indicate the opening steps.
- All the wires should be fixed in the bottom case, so that all the components could be plugged and unplugged easily without wires attached, since there's no use to recycle the wires.
- We need to remind user to open the keyboard case by printing the instruction symbol in the back (or side edge) of keyboard tray.

4.4 Workflow

4.4.1 Workflow

The following graphic illustrates the Autodesk team's design workflow for the project. The workflow is, in essence, a simplified summary of the team's design development process.

Figure 67 *Workflow summarizing design process*

On Digital Prototyping

For the initial concept phase of various design elements, such as latch mechanisms, the team found that quick pencil/paper sketches or cardboard mock-ups were more effective than digital prototyping. Fast hand sketches allow for more rapid ideation and iteration; most designers find CAD modeling to be too time consuming to use during this early phase in the design process. However, CAD tools were utilized later on in the development process when the team had a more focused concept of the final solution design.

Also, when designing new experience designs, it is imperative that the designs are tested with people. The best way to do this (and the way that Stanford teaches it) is to construct *physical* mock-ups of a prototype and then put it into the hands of users to see how they react to it. This prototyping process is most useful during the initial design development stages, when the team is exploring a number of design concepts, but remains important throughout the process as a means of testing and verifying the developing design features. It is for this reason (and the team's goal to develop a physical product solution) that the Autodesk team most often used physical prototyping methods instead of digital prototyping tools.

5 Design Specifications

5.1.1 Overview

Figure 68 *Bloom laptop prototype*

The **Bloom** laptop was constructed using electronic components from an aluminum 2009 Macbook and an SLA printed ABS plastic case. Necessary peripheral electronics such as batteries and USB extenders were purchased from Fry's Electronics, and the friction hinges and slide mechanism pieces were manufactured in the Product Realization Lab (PRL) on the lathe and LaserCAMM, respectively. For a complete list of materials and manufacturing processes see section 5.1.3.

The team had planned to mill the original case from aluminum (70-71) but due to time and monetary restraints the prototype was manufactured with SLA 3D-printing processes instead. The proceeding design specifications are therefore specific to the SLA process employed by the team for the EXPE prototype. All of the necessary CAD files can be found online at the following web address:

URL	Password
http://drop.io/bloomCAD	suomi

Table 10 *Final Solution CAD files*

Use of the above website listed in Table 10 is highly encouraged as the 3D models present a clear and easy method for examining and reproducing the prototype (see Figure 69 for example of CAD model). The design specifications in this document are almost entirely derived from the 3D models available online.

Figure 69 *Bloom: Final rendered CAD model*

5.1.2 Core Electronics

In order to create the final product, the design team required functioning hardware from another laptop. This section describes the hardware that was chosen and the modifications made before it was used in the final laptop.

Hardware Description

The hardware that was chosen was from a 2009 MacBook from Apple, Inc. The hardware included one motherboard with attached hard drive, RAM, heatsink, and fan. Attached to this motherboard were one battery, one keyboard (with power button), three speakers, one wireless antenna and circuitry, and one webcam with attached microphone. Charging the battery was accomplished via the provided adapter.

The wireless keyboard was chosen simply based on the thickness of the hardware. The thinnest hardware purchased was the Adesso WKB-4000UB, which is a 2.4 GHz wireless keyboard with USB connection. This hardware was modified as well so that it could fit the needs of the design team.

Hardware Modifications

The team modified the MacBook and wireless keyboard hardware so that it could be oriented differently than in the MacBook casing, but in such a way that it was still functional. The list of modifications is listed below in Table 11:

Part Modified	Modification Made	What Was Required
Cable connecting battery and motherboard	Cable extended by 6 inches	Solder additional wire to existing cables
Cable connecting charging PCB (magnetic) and motherboard	Cable extended by 9 inches	Solder additional wire to existing cables
Cables connecting speakers with motherboard	Cable extended by 9 inches	Solder additional wire to existing cables
Power button	Removed power button from MacBook keyboard, replaced it with larger push button	Solder wire to the pins on the motherboard corresponding to the power button; connect this wire to the new power button
PCB in wireless keyboard hardware	Removed this PCB, rerouted surrounding connections so that keyboard remained functional	Unsolder connections to this PCB and reroute to main logic board
Capacitors on main logic board in wireless keyboard hardware	Removed these capacitors from their surface mounts and attached them to wires to make keyboard thinner	Remove solder holding capacitors in place; resolder them onto the ends of wires

Table 11 *List of modifications made to all laptop hardware*

5.1.3 Bill of Materials

Assembly	Sub-Assembly	Parts	Qty.	Material	Manufacturer
Screen	Back	Frame	1	ABS Plastic	Prototypes Plus - SLA
	Press Fits	Post guides	16	Acrylic	PRL - LaserCAMM
	Front	Frame	1	ABS Plastic	Prototypes Plus - SLA
	LCD Screen	LCD and cabling	1	2009 Aluminum Macbook	Apple
	Web Camera Assembly	Web Camera and associated circuitry	1	2009 Aluminum Macbook	Apple
Hinge		Nuts	4	Aluminum (60-61)	Mcmaster-Carr
		Spring washers	4	Steel	Mcmaster-Carr
		Body	2	Aluminum (60-61)	PRL - Lathe
Base	Bottom	Frame	1	ABS Plastic	Prototypes Plus - SLA
	Front Hatch	Frame	1	ABS Plastic	Prototypes Plus - SLA
	Back Hatch	Frame	1	ABS Plastic	Prototypes Plus - SLA
	Small Speaker Holder	Holder	1	ABS Plastic	Prototypes Plus - SLA
	Large Speaker Holder	Holder	1	ABS Plastic	Prototypes Plus - SLA
	Computer Hardware	Charging PCB/Battery/Motherboard/Wireless Card/Fan/RAM/Hard Drive/USB Extender/Speakers/Power Button/All Necessary Wiring	1 (each)	Computer Hardware – 2009 Aluminum Macbook	Apple
Keyboard	Front	Frame	1	ABS Plastic	Prototypes Plus - SLA
	Back	Frame	1	ABS Plastic	Prototypes Plus - SLA
	Keyboard Hardware	Trackpad/Keyboard/Wireless Transmitter/Wireless Receiver	1 (each)	Computer Hardware	WKB-4000UB Wireless Keyboard
	Battery		1	Li-ion	Nokia

Table 12 *Bill of materials*

5.1.4 Screen Case

The Screen Case is composed of two SLA-manufactured parts, called Screen Front and Screen Back, that lock together to hold the LCD and web camera securely in place. The Screen Back contains 16 depression areas into which identical acrylic post guides are press-fitted and super-glued into place. An exploded view of the assembly is seen in Figure 70 and Figure 71, offering two perspectives of the same assembly. Note the posts on the interior of the Front Screen, which lock into the Post Guides, which are press fit into the Screen Back.

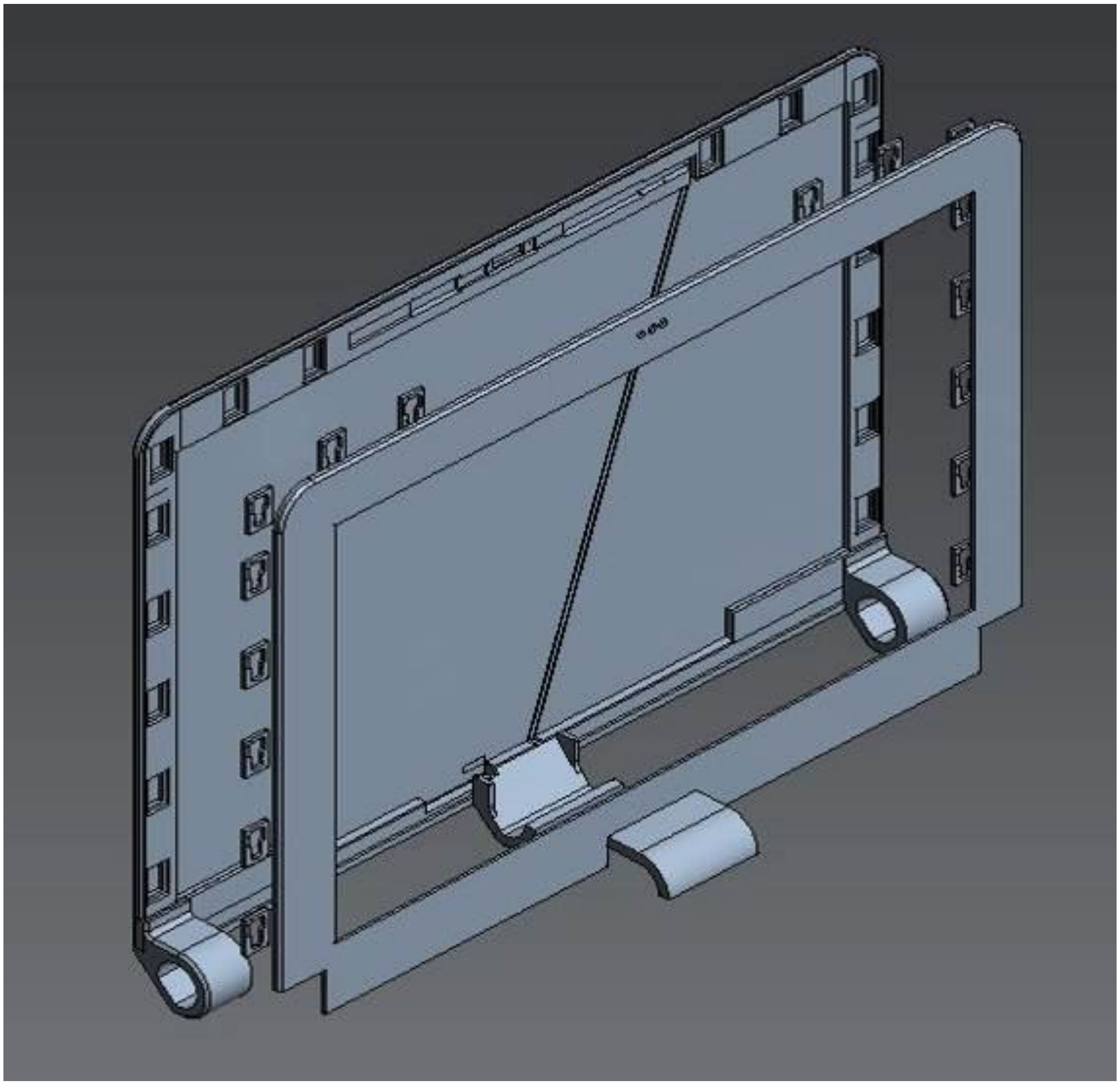

Figure 70 *Exploded Screen Assembly, Perspective #1*

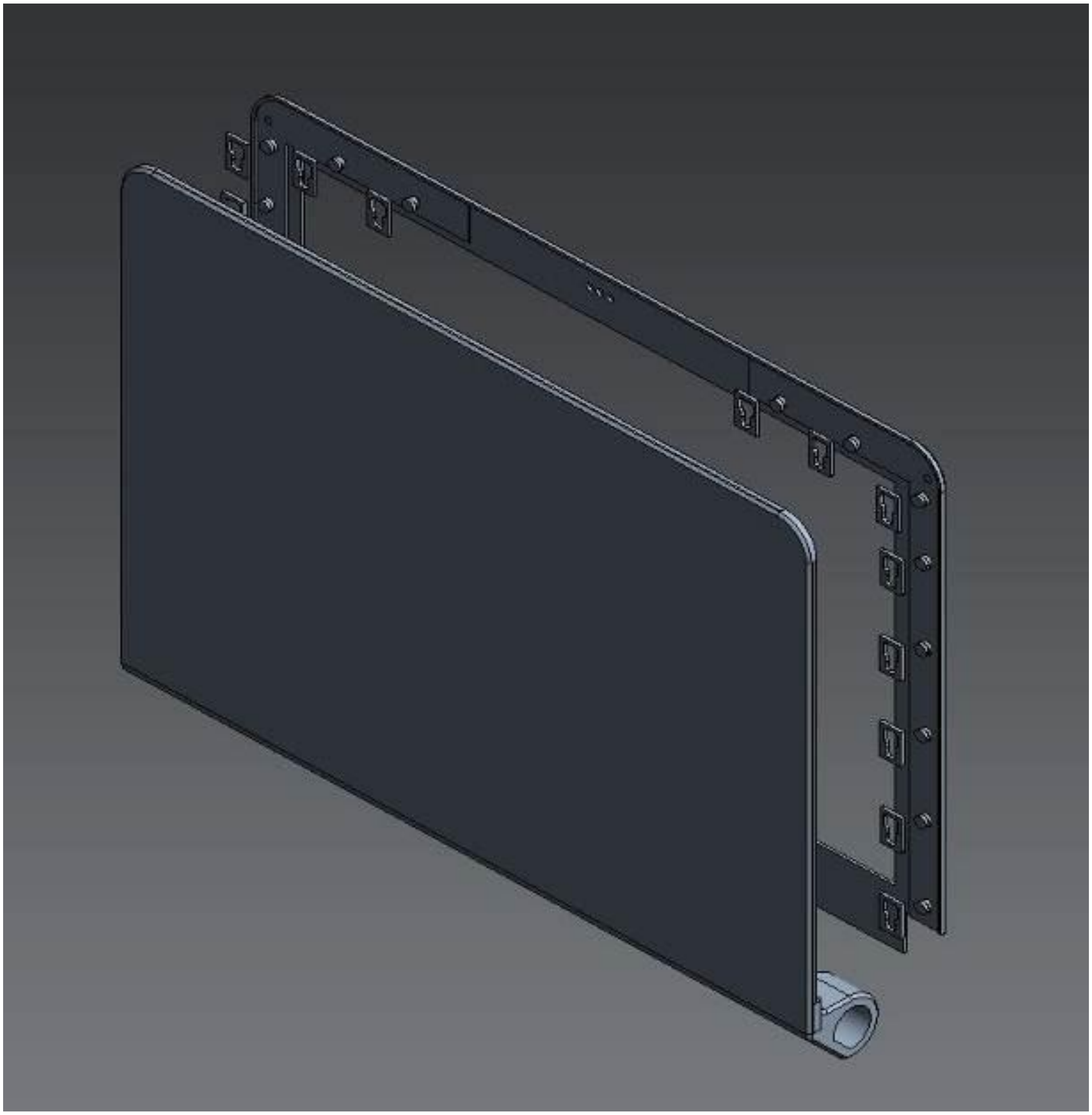

Figure 71 *Screen Assembly, Perspective #2*

Dimensions

Detailed dimensions of the Screen Case can be seen in Figure 72 through 74. Note the scaling on Figure 74 is 10:1.

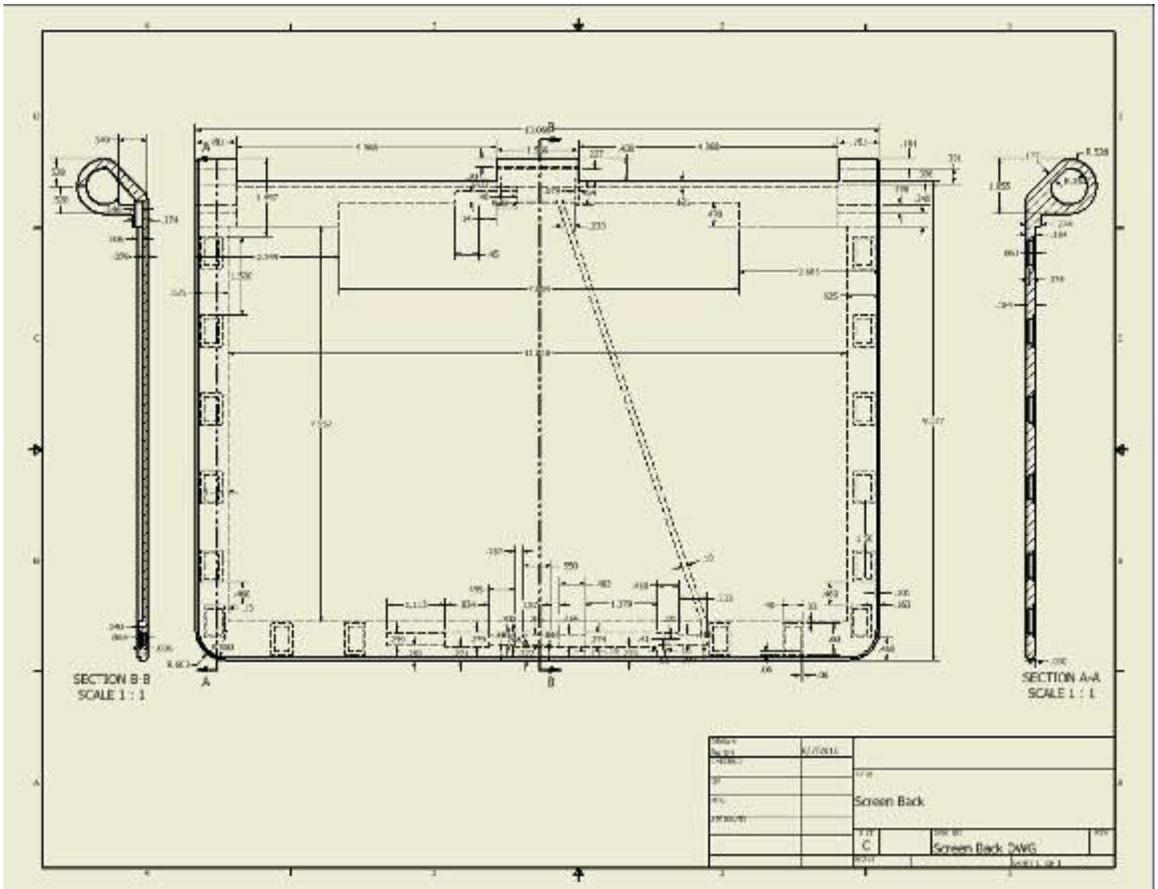

Figure 72 *Screen back - dimensions*

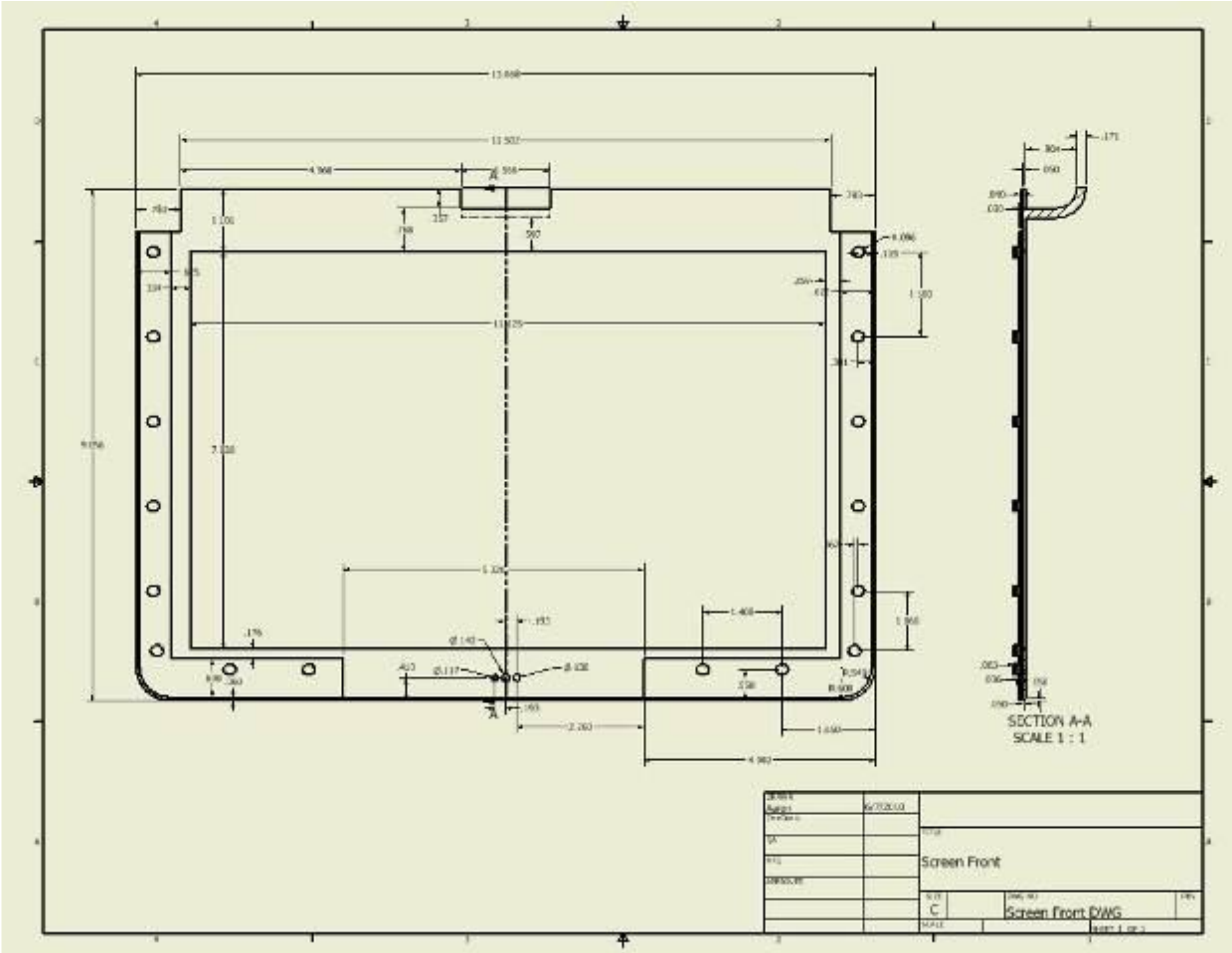

Figure 73 *Screen front - dimensions*

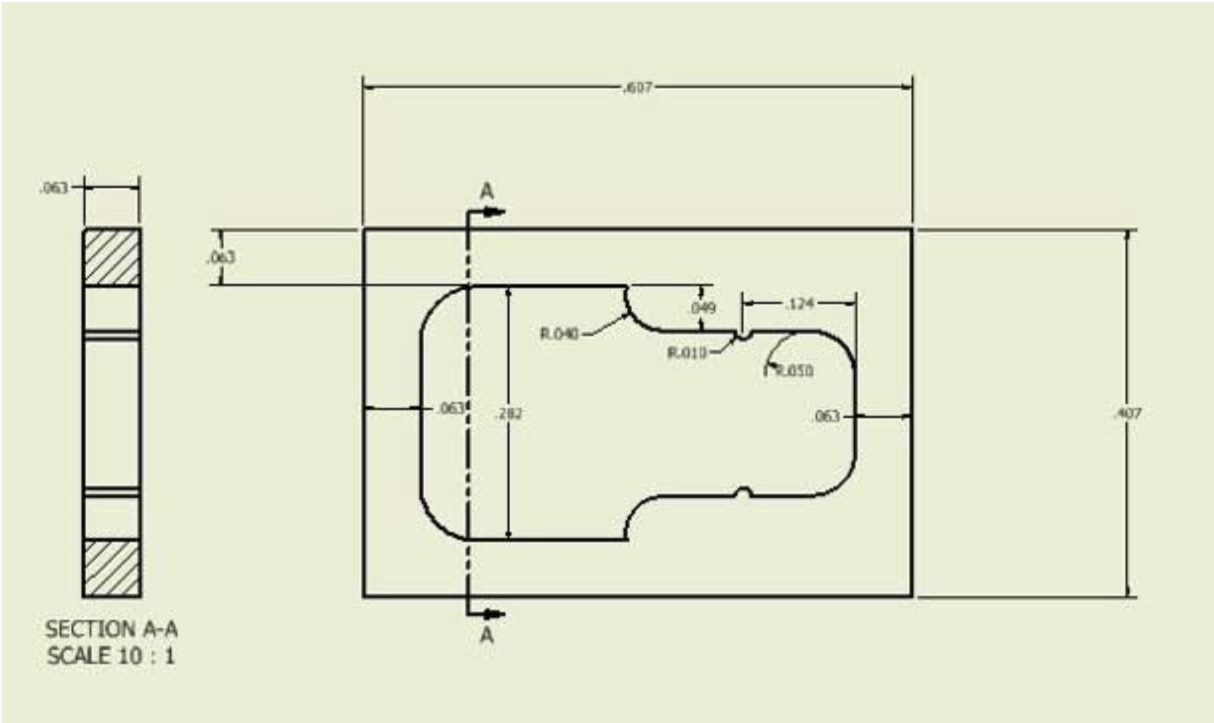

Figure 74 *Post guide - dimensions*

Mechanisms

As previously mentioned, the Screen Front was designed to slide upwards in order to be released from Screen Back. Close inspection will reveal a few surprising dimensions in the Post Guides responsible for this sliding mechanism however. The Post Guides dimensions are slightly larger than the depressions within the interior of the Screen Back because the method of Post Guide manufacture (a PRL LaserCAMM) has a laser thickness of ~.01 inches. Furthermore, as can be inferred from the dimension drawings, the Post Guides are meant to be laser cut in 1/16 inch acrylic sheets.

Hardware Security

The LCD and web camera are the only hardware components designed to fit in the Screen Case. The LCD is held in place by friction between the Screen Front and Screen Back. This friction is aided by the porous rubber foam encircling the LCD, which is purposefully not removed during Macbook disassembly. The web camera is light enough to be reliably held in place by the perfectly sized depression cut into the interior of the Screen Back. The wires on the web camera are also purposefully not flattened to aid in the "snugness" of the web camera. The diagonal groove on the interior of the Screen Back is cut in order to allow room for the web camera wiring. For both the LCD cable and web camera cable the insulating sheath of tape is removed before placement into the Screen Case.

5.1.5 Base & Hatch Assembly

The Base and Hatch assembly contained the majority of the laptop hardware and served as the base of the laptop itself. The hardware was taken from a 2009 Aluminum Macbook while the case was SLA printed. In addition to housing the laptop hardware the Base also contained the two speaker frames and hinge axle. Many components were present in the base and these are outlined in Figure 75.

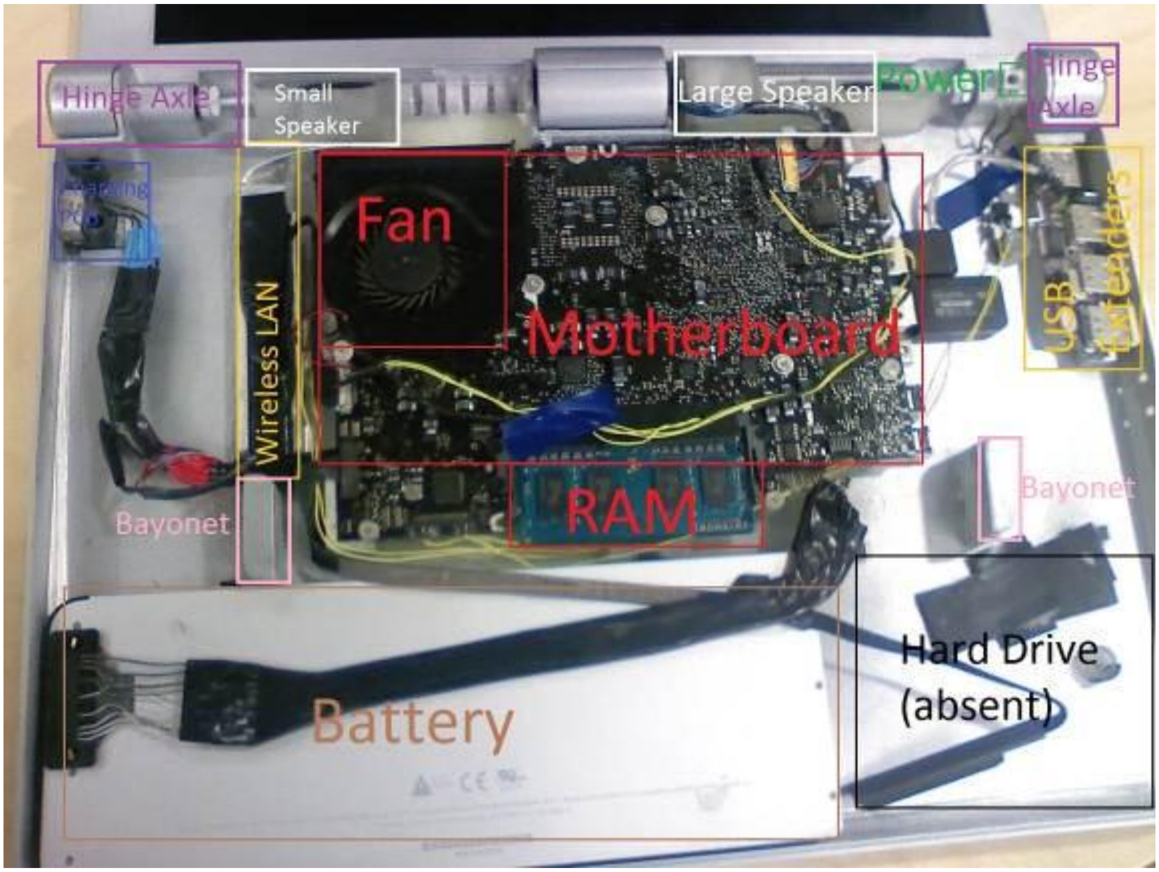

Figure 75 *Internal layout for laptop base*

As is described in the hardware section, spacers are added to the hardware to give each component the proper depth to sit tightly within the Base and Hatch assembly. After manufacturing the Hinge Axles they are placed in the appropriate location as in Figure 75in order to join the Base and Screen Back. The Bayonets are also placed into the appropriate slots and the bayonet pins inserted into the bottom hole on the bayonet shaft in order to lock them down and prevent vertical motion of the bayonet.

Before placing the speakers within the 3D printed speaker cases the subwoofer lid is superglued onto the side of the large speaker case (such that the overall shape remains unchanged).

Exploded views of the Base and Hatch assembly are shown in Figure 76 in order to further illustrate the overall construction of the laptop from components .

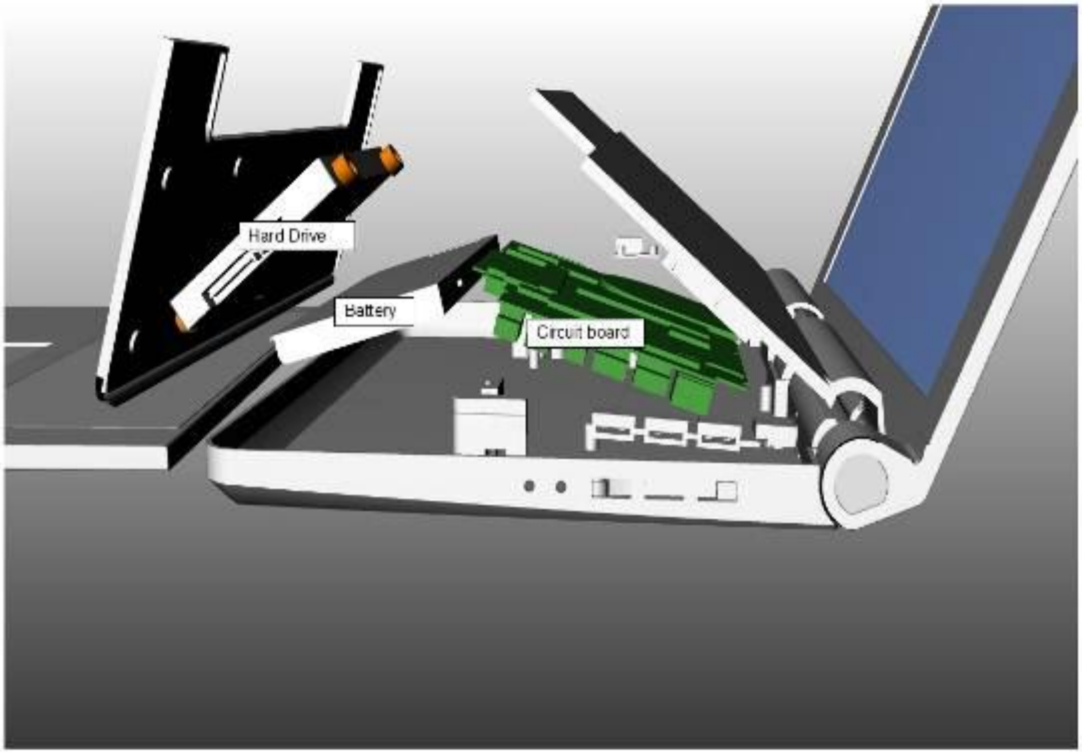

Figure 76 *Exploded view of Bloom with open hatches*

Dimensions

Detailed descriptions of all 3D printed parts with appropriate dimensions are as follows.

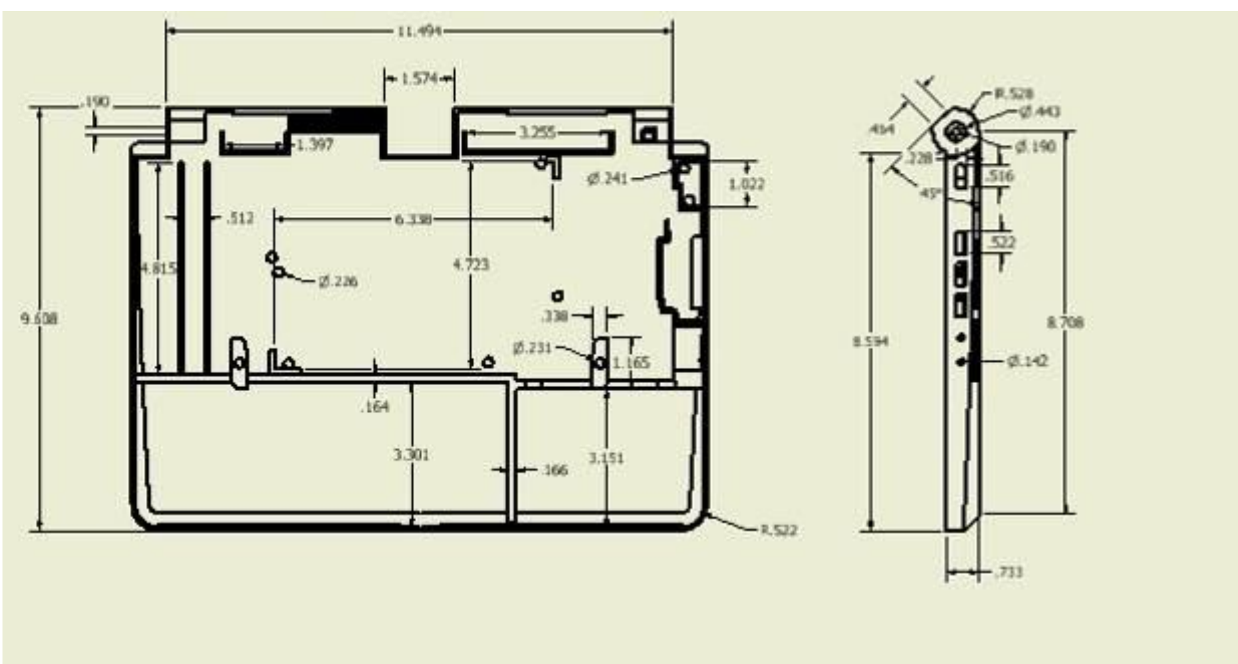

Figure 77 *Base dimensions*

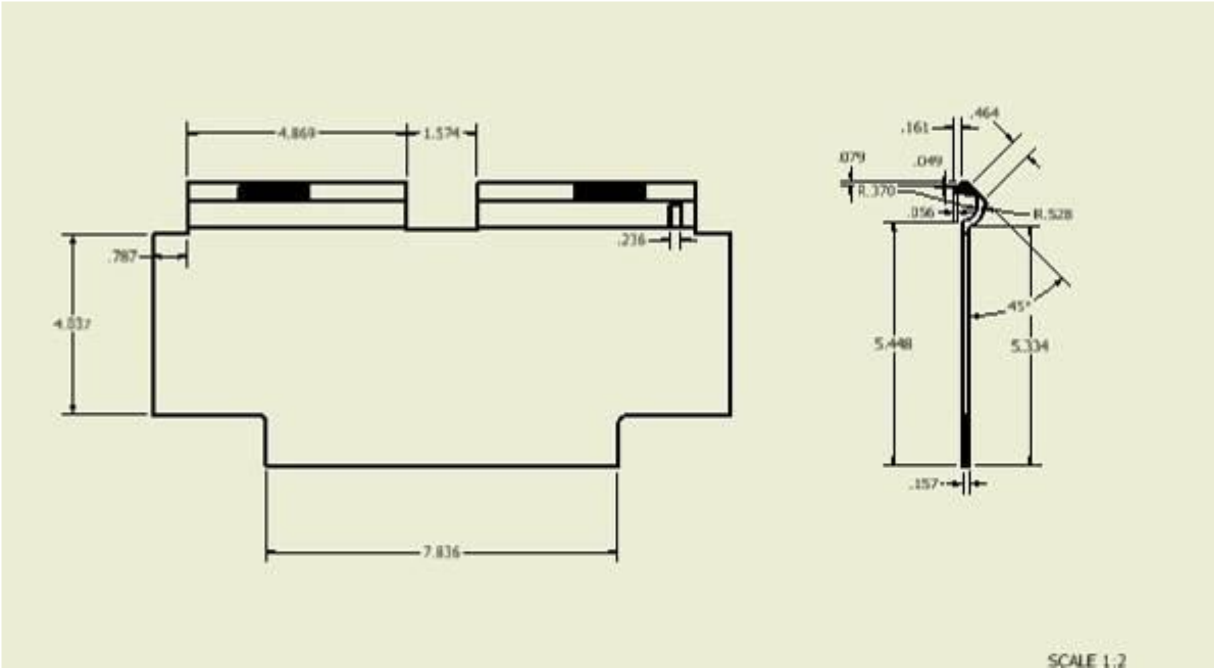

Figure 78 *Back hatch*

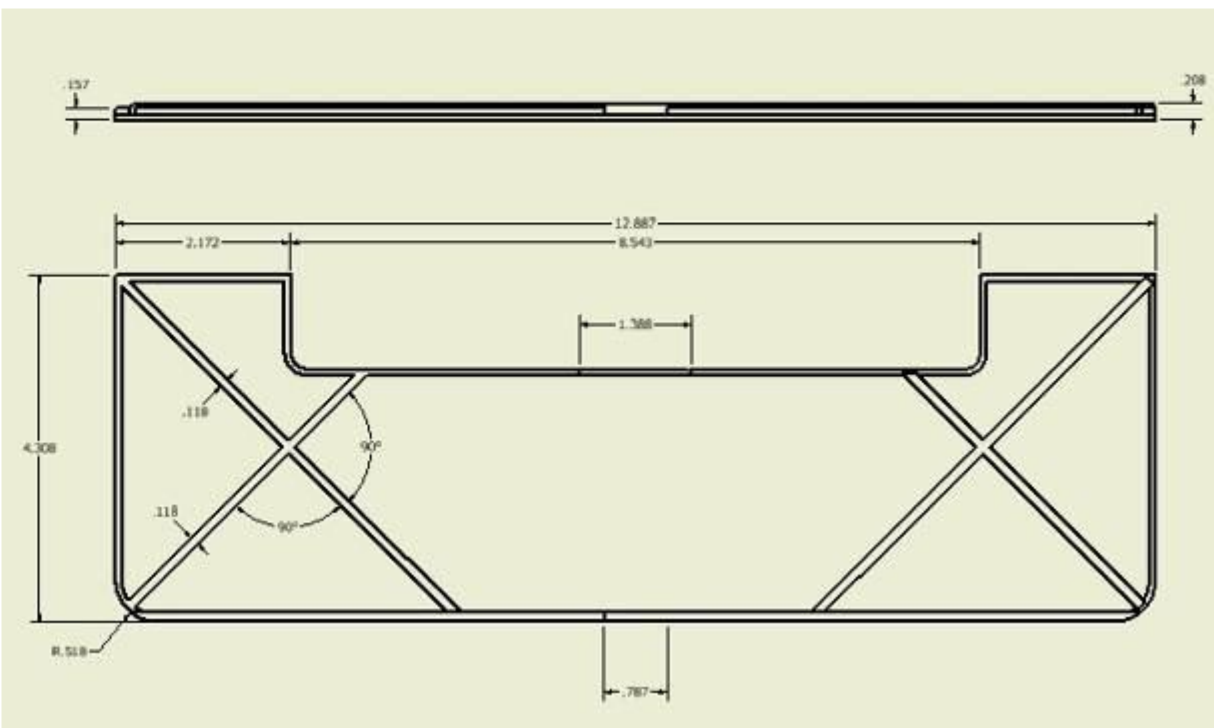

Figure 79 *Front hatch*

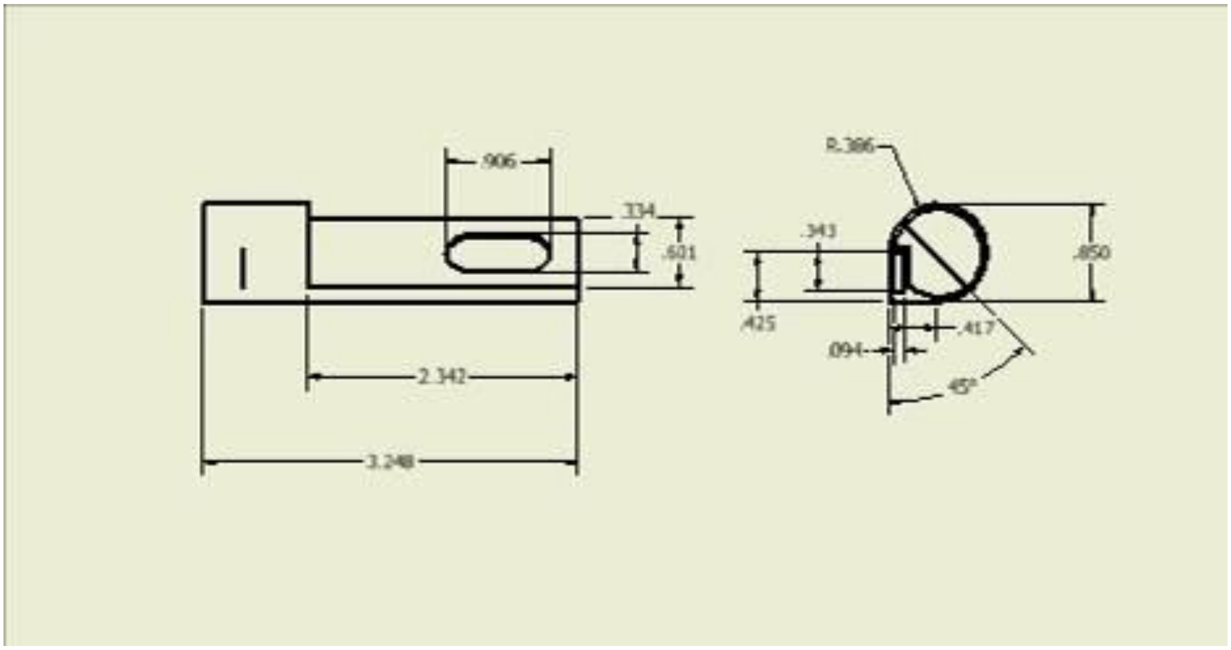

Figure 80 *Larger speaker case*

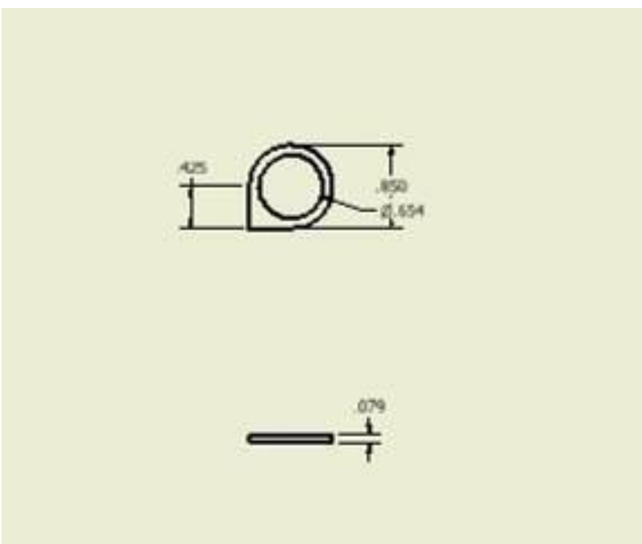

Figure 81 *Subwoofer lid*

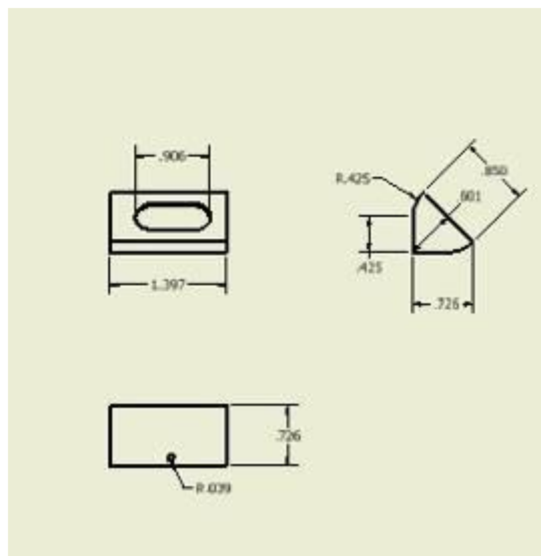

Figure 82 *Small speaker*

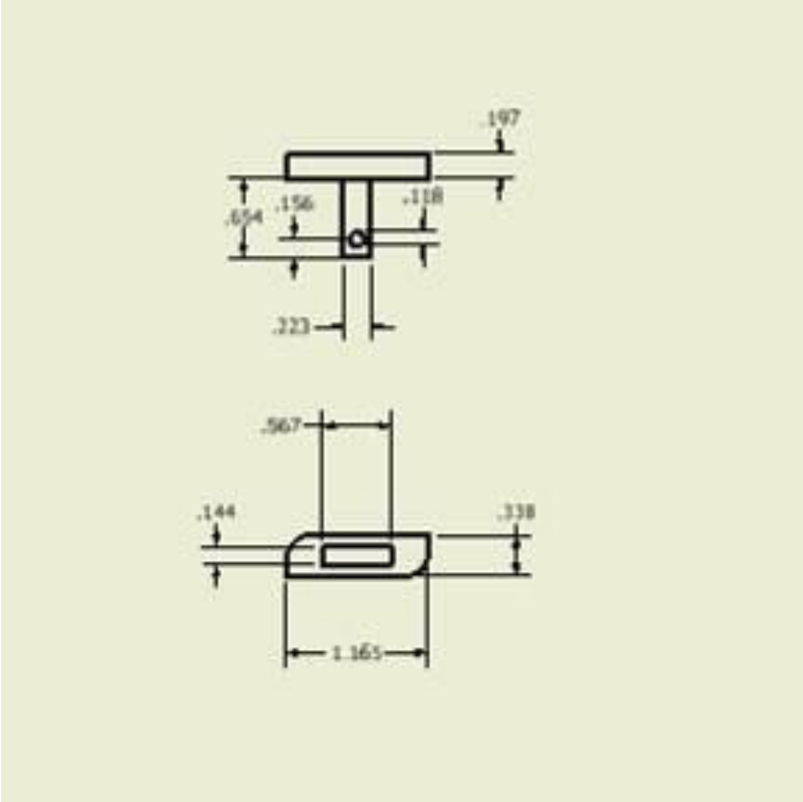

Figure 83 *Bayonet left (right is a mirror image of left)*

Mechanisms

The locking mechanism for the Hatches required that both Hatches be secured by the edge of the Base as well as by the Bayonets. The Back Hatch fitted into notches in the Base near the Screen Back (see figures above for reference). The Front Hatch fitted into a notch at the front end of the Base (see Figure 77 for reference). The Bayonets then held the Hatches down when turned to the closed position. Figure 84 and Figure 85 demonstrate this extremely simple opening mechanism.

Figure 84 *Bayonet hinge closed*

Figure 85 *Bayonet hinge open*

The pins inserted into the bottom of the Bayonets during construction prevented the Bayonets from moving vertically and provided the necessary force to hold the Hatches in place. On release of the Bayonets the Hatches open upwards and slide free as in Figure 69.

Hardware Security

When properly closed the two hatches are held down tightly by the twin bayonets on the left and right side. These bayonets in turn provide the pressure that holds the hatches flush against the laptop hardware. This pressure prevents vertical motion of the hardware while the precisely placed structures on the interior of the Base prevent lateral motion. The speaker cases (both the Large Speaker and Small Speaker) will similarly be held in place through friction. When the bayonets are oriented in the closed position (locking the hatches down) the wireless keyboard will sit flush with the bayonets securely fitting in an indentation in the Keyboard Back.

5.1.6 Hinge

The hinge was manufactured in the PRL on the lathe. The threading was 10-32 and all parts were made/purchased from aluminum except for the spring washers, which are steel.

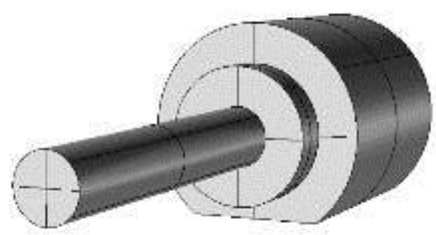

Figure 86 *CAD model of hinge axle*

Dimensions

Details of the dimensions of the Hinge are shown Figure 87.

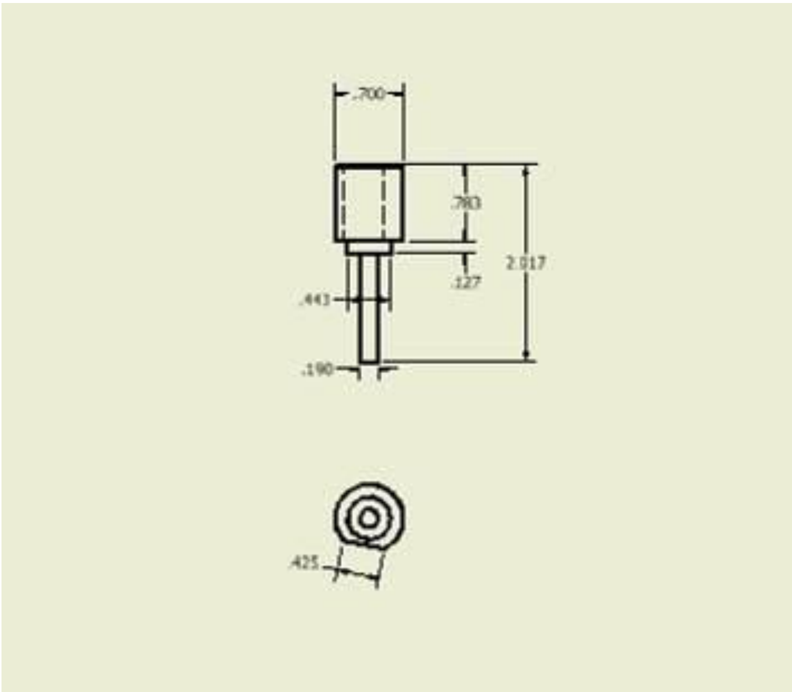

Figure 87 *Hinge axle*

5.1.7 Keyboard Case

The Keyboard Case is composed of two SLA manufactured parts (Keyboard Front and Keyboard Back) that lock together when properly closed and hold the wireless keyboard hardware securely in place. The Keyboard Front contains 8 depression areas into which identical acrylic post guides are press fit and superglued into place. An exploded view of the assembly is seen in Figure 88 and Figure 89,offering two perspectives of the same assembly. Note the posts on the interior of the Keyboard Back, which lock into the Post Guides which are press fit into the Keyboard.

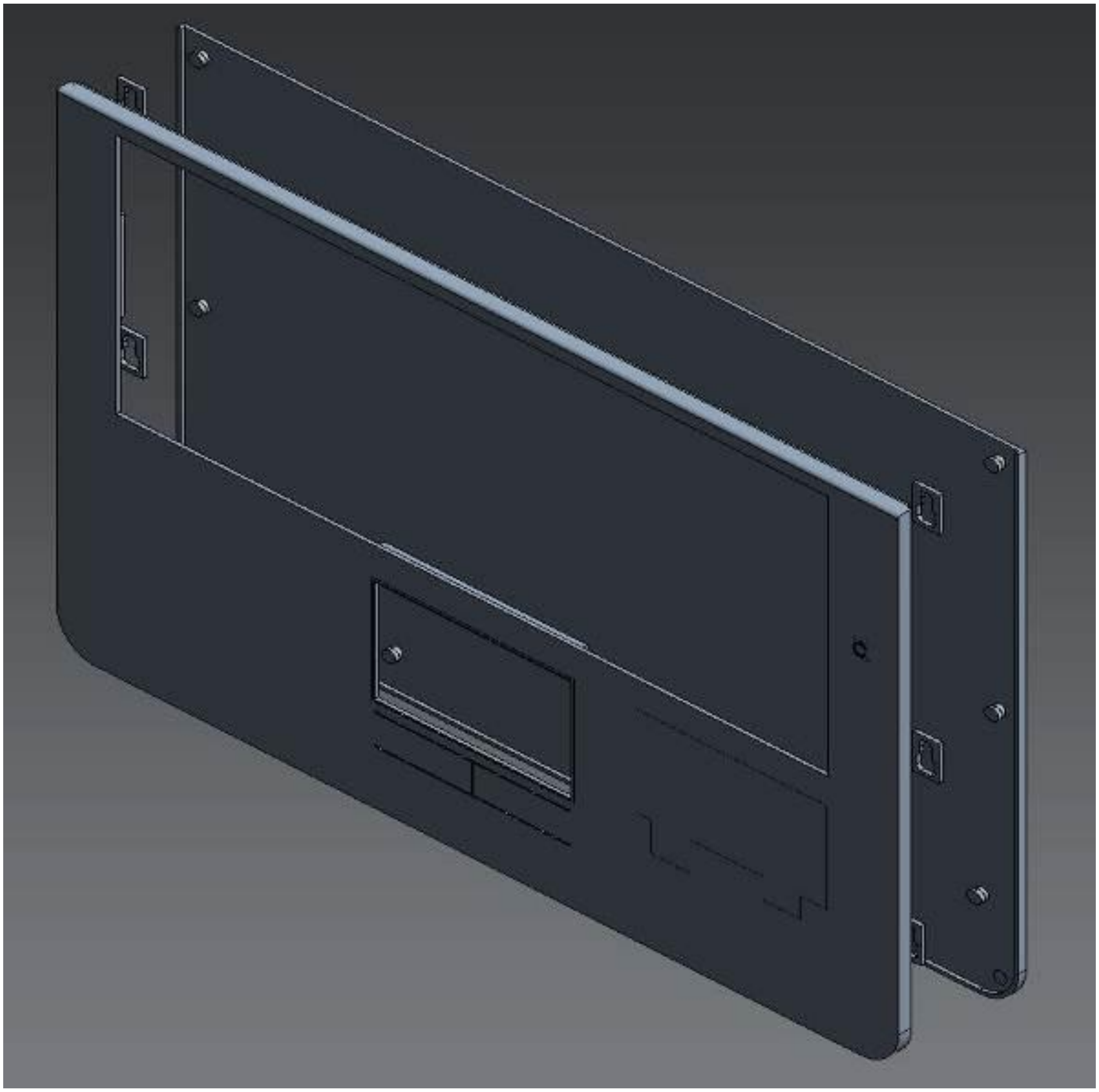

Figure 88 *Keyboard disassembly, perspective #1*

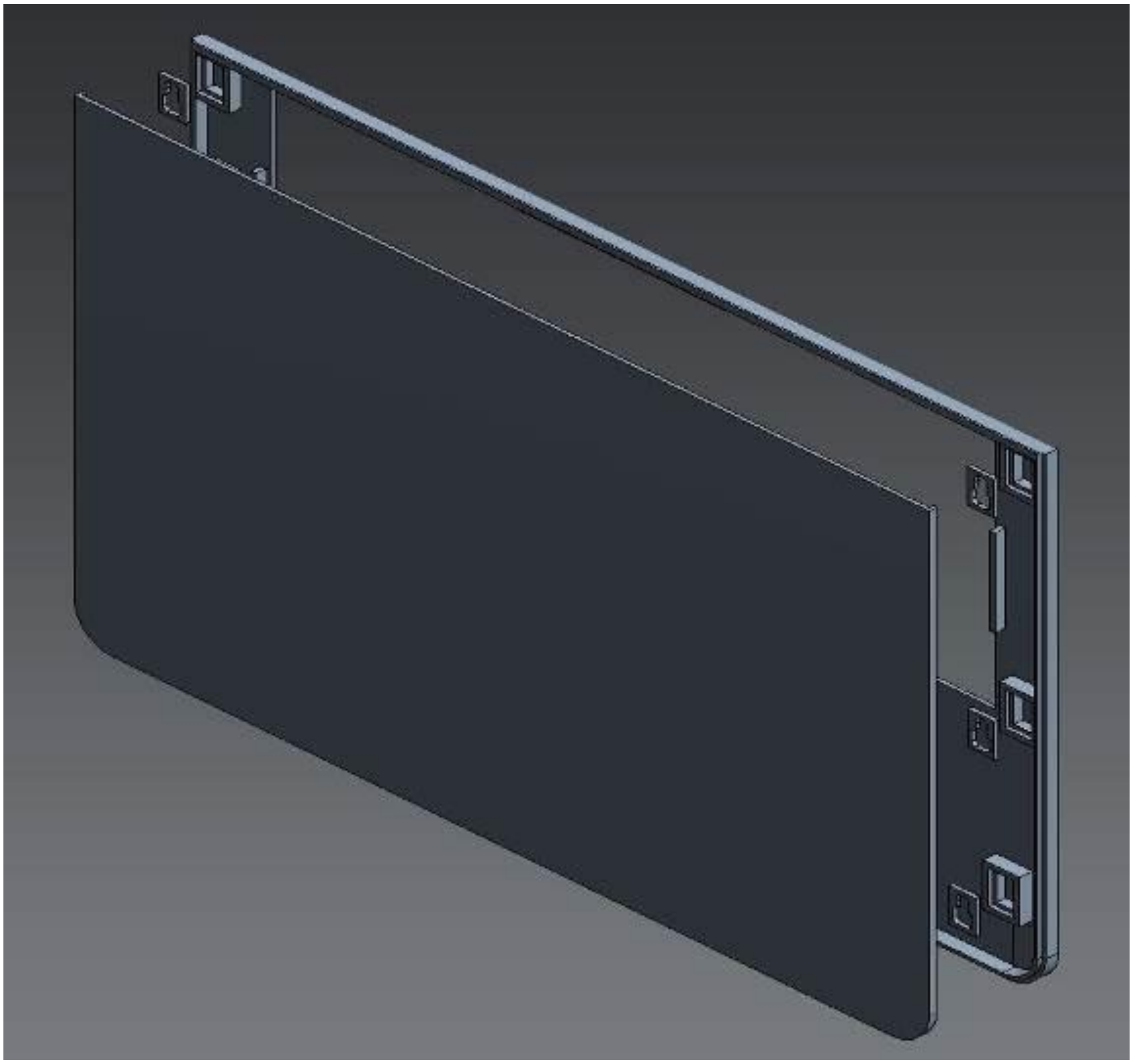

Figure 89 *Keyboard assembly, perspective #2*

The wireless keyboard hardware is then placed into the appropriate grooves in the Keyboard Front which prevent lateral movement. The Keyboard Back then holds the hardware securely in place as it locks in tightly with the post guides. A diagram illustrating the proper placement of circuitry into the interior of the Keyboard Front is shown Figure 90.

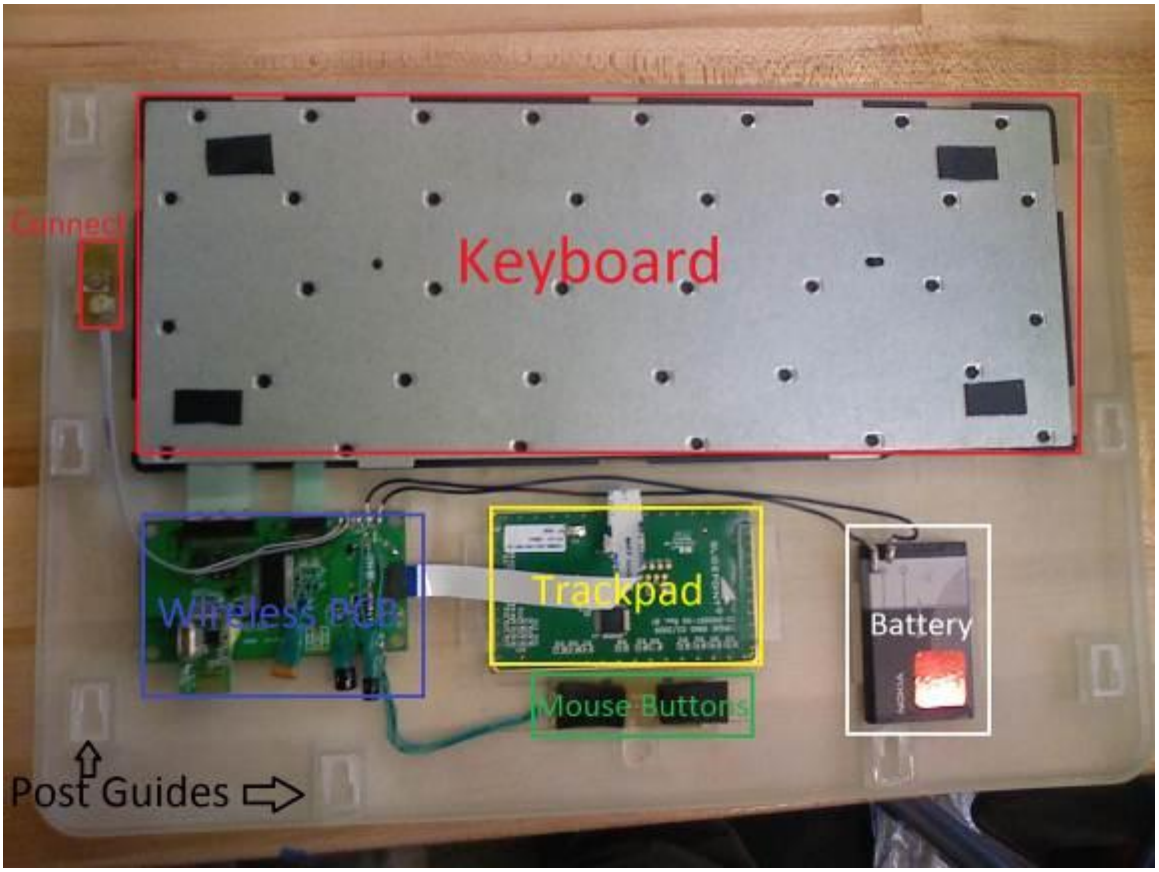

Figure 90 *Placement of circuitry within keyboard front*

Dimensions

Detailed dimensions can be seen in the following drawing files. The Post Guides used in the keyboard assembly are the same as those used in the screen assembly so the dimensions will not be reiterated. Please note that again these files, as well as the full 3D models, can be found online at the website referenced in the beginning of the Design Specifications section.

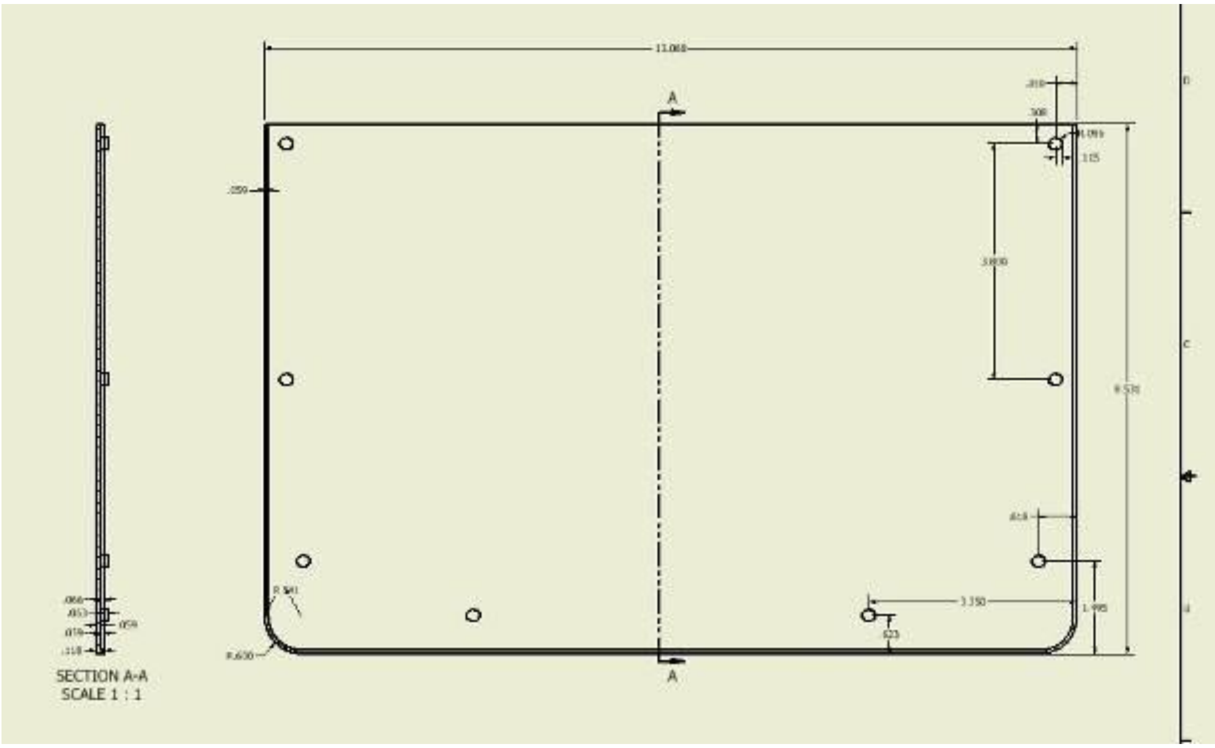

Figure 91 *Keyboard back*

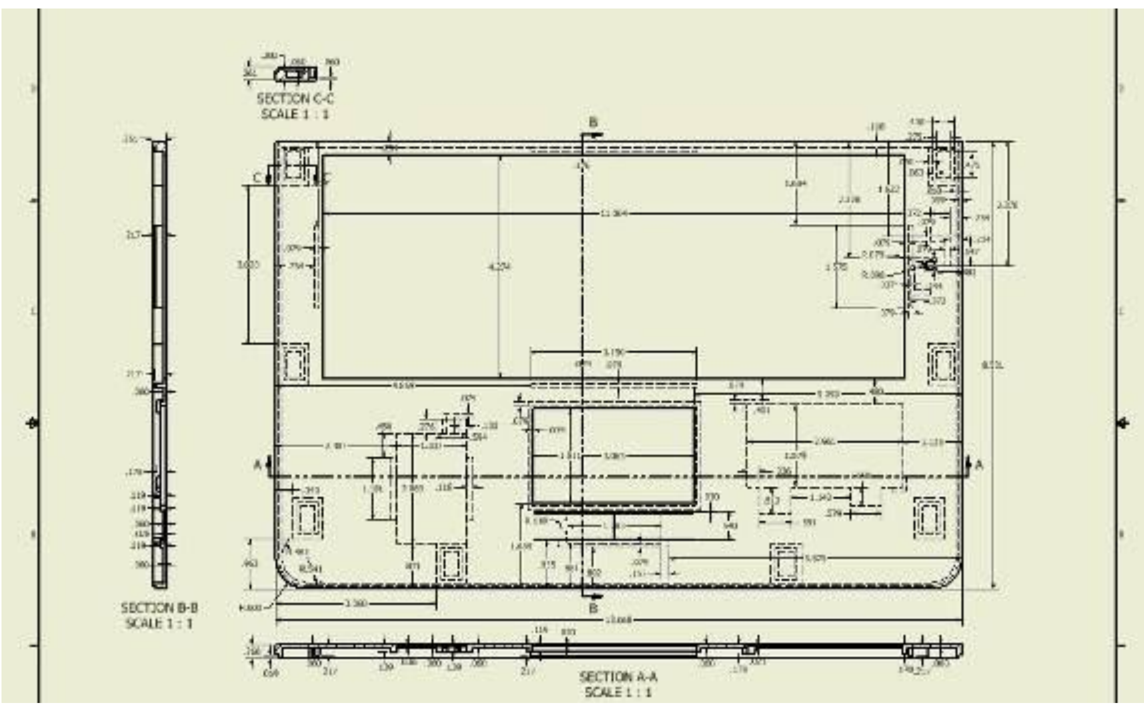

Figure 92 *Keyboard front*

Mechanisms

Similar to the screen case mechanism, the Keyboard Back is designed to slide upwards in order to be released from the Keyboard Front. The lip and curved edges on three sides of the keyboard assembly prevent the keyboard from sliding in any undesired direction – as well as adding to the aesthetic appearance. All mechanisms for sliding are identical to those found in the screen assembly.

Hardware Security

The keyboard assembly contains many loose circuitboard components that are held in place by the precise grooves cut into the interior of the Keyboard Front. Closing the keyboard assembly requires careful placement of the circuitry in order to assure proper alignment (for proper placement demonstration see Figure 90). As described in the Hardware section, spacers of different materials such as acrylic were used to give the circuitboards inside the keyboard assembly the proper depth to cause a "snug fit" once the assembly was closed.

6 Project Planning and Management

6.1 Deliverables & Milestones

6.1.1 Fall

November 10th - Needfinding and Bencmarking Review

November 19th – Critical Function Prototype

December 1st – Fall Design Abstract

December 3rd – Fall presentations

December 8th – Fall documentation

See Appendix H for more timeline and budget details from fall term.

6.1.2 Winter

January 19th – Dark Horse Prototype

February 2nd – Funky Prototype

February 11th – Winter presentations

March 11th - Functional System Design Review

March 16th - Winter Documentation

Continue user testing functional system prototypes to gain more insights regarding design effectiveness

See Appendix H for more timeline and budget details from winter term.

6.1.3 Spring Deliverables

Date	Deliverable	Description
5 April	Establish final set of POVs	Who are the primary users and what are their needs?
7 April	Identify the X component	Choose the component / functionality for "X is Finished" deliverable. Establish metrics for testing the component and design user testing.
7 April	Design X	Begin designing and prototyping X
14 April	User tests	Run user tests with prototypes of X
21 April	**X is Finished**	Get one (non-trivial) part "X"of the design into its final form. This could be something that you send out for fabrication. Pick a part of your design that you are pretty settled on, get it out of the way so that you can check it off on your "to do" list.
23 April	Recap / documentation	"X is finished" debrief. Begin documentation of design development for prototype.
28 April	Define internal components	What hardware components are going to be used in final solution
28 April	LCA	Conduct life-cycle analysis of product solution. Decide which design elements we take for granted.
3 May	Design casing	Final CAD model for case component of laptop.
7 May	**Freeze the Design**	
16 May	Prep Hardware for display	Finish hardware integration and prepare for presentation
18 May	**Penultimate Hardware Review**	The main purpose of this assignment is to increase the chances of a polished final product on June 4th. It is a project planning milestone set by the TTeam -- based on past experience in the course.
20 May	Recap / documentation	Debrief of Hardware Review. Update documentation of design development.
26 May	Final Brochure and Poster for EXPE (soft copy)	Poster will help give an overview to people who walk up to your booth, and also be a great visual for you to speak to. Afterwards, it comes up to the loft and is ceremoniously hung up with the posters of years past.
28 May	**Final Brochure and Poster for EXPE (hard copies)**	What we learned during the fall? Any new ideas for the spring?
3 June	**Final Hardware Review (EXPE)**	ME 310 and ME Design Department project expo.
8 June	**Final Documentation**	Create a document describing in detail the team's complete product, design process, and lessons learned during spring quarter.

6.2 Project Time Line

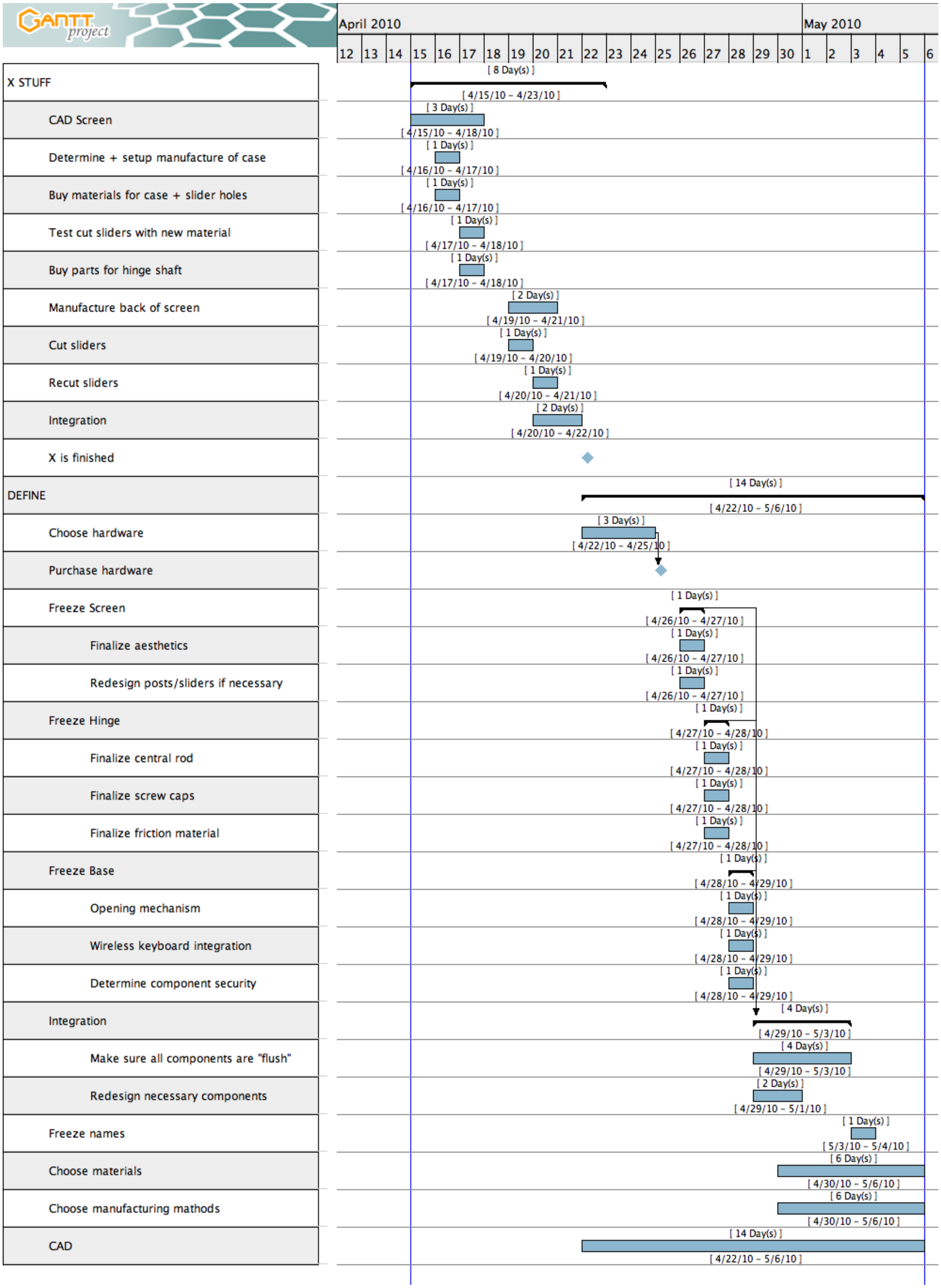

Figure 93 *Spring timeline: April 14 - May 5*

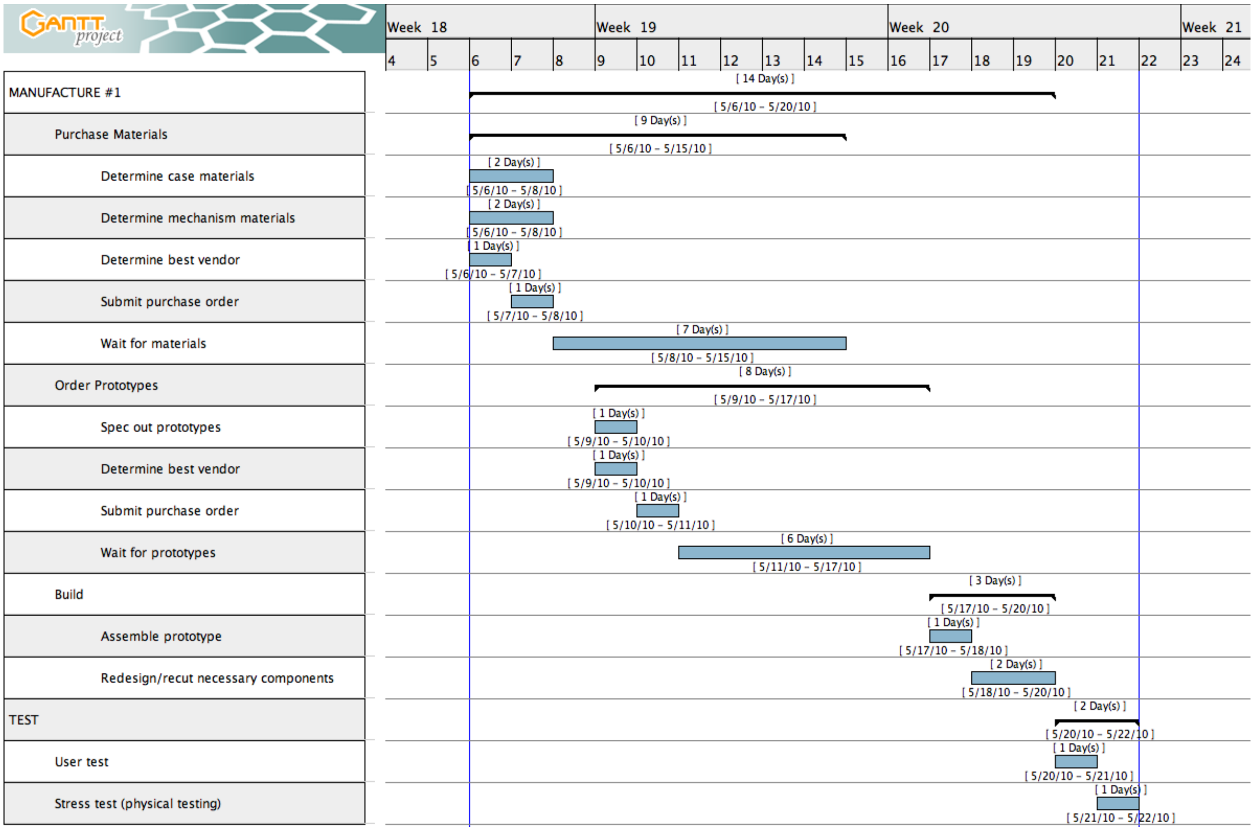

Figure 94 *Spring timeline: May 6 - May 21*

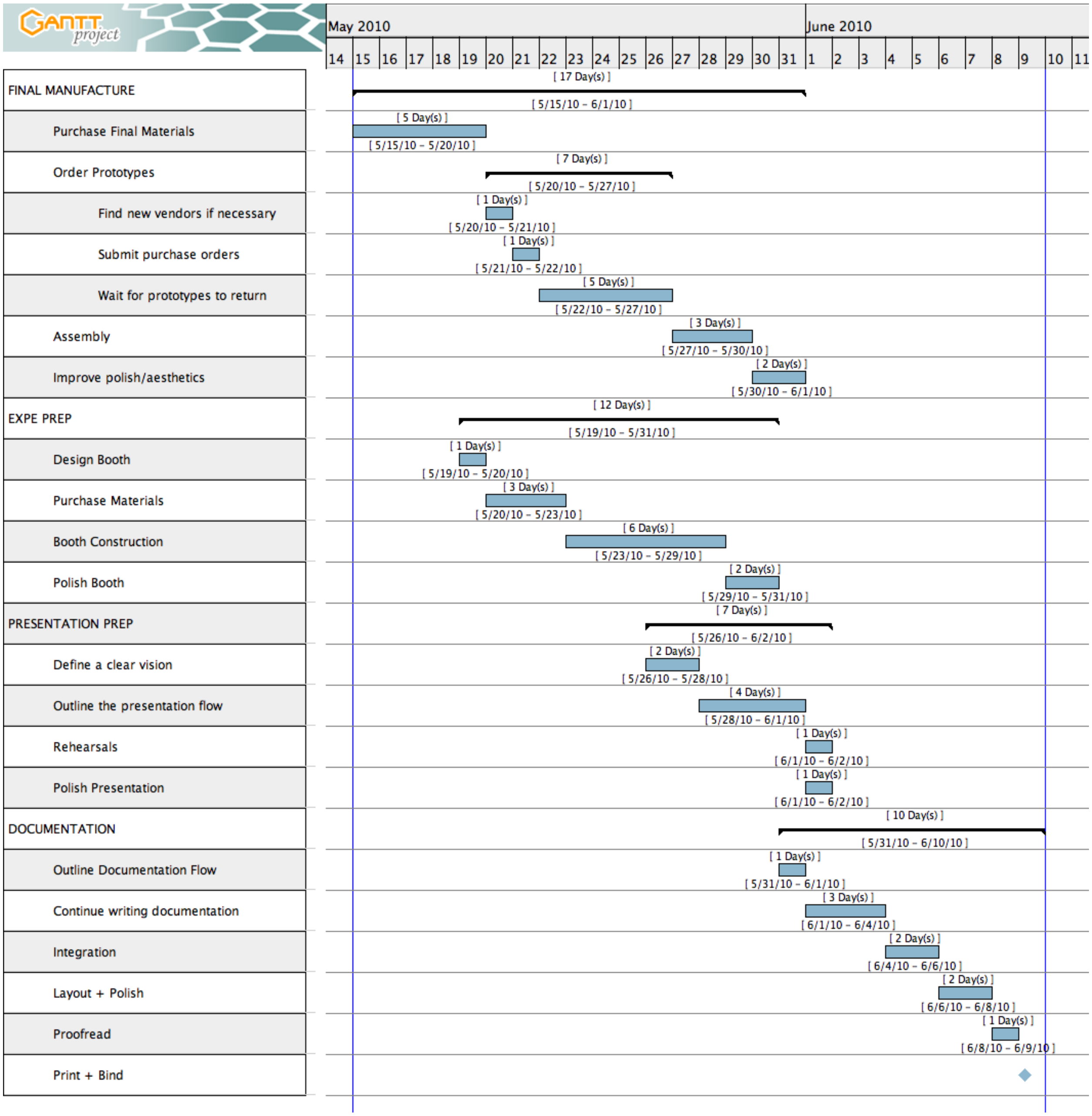

Figure 95 *Spring timeline: May 15 - June 8*

Final Two-Week Timeline

Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
- Plan EXPE experience [design, materials, tasks] - Plan out remainder of documentation [timeline, tasks] - Design e-waste structure **- Prototype1 ORDERED** - K: Build hinge - A: LaserCAMM stuff - J: Laptop ID	- Maker fair? - K: Re-build hinge if necessary - J: Laptop ID	**- Experience plan details DONE** - Final BOM for EXPE [and where to get stuff] - Maker Fair: collect e-waste - J, M: CAD touch-ups - R: Keyboard stuff	**- Poster and product promotion content DONE** **- Booth layout and BOM DONE**	- Design posters and promotional items DONE - Decide name and tagline / all - Decide which logo and which visual style / all - Revise the message we want to give - Feature list -> annotations for the poster / Juho, Markku**,** - Pictures out of the laptop for the poster. - Secure the bartables & stools / Americans - Go get the Macbook (Finns figure out the payments with international moneytransfers) / Linda - User tests on disassembly guidance / Chongbei -> feedback for CAD-team.	**- Pick up prototype1** - Assemble - Make design changes - CAD **- CONTINUE USER TESTS:** a) Ease of disassembly. b) Ease of upgrade. Finish the brochure and poster / Chongbei, Kirsten, Rohan, Linda	**- Finish and order poster (K)** **- Place the t-shirt order/Linda** **- Final prototype(s) ORDERED, Finns pay / Rohan, Linda** **- Laptop timelapse video?** - Figure out the grass sod resellers, place an order/reservation / (K) - Build tower (K, A)?? **<u>SGM, LGM, SUDS</u>**

Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
- Pick up poster (K) - Build tower (K, A, R) - Outline presentation - Touch up proto1 - Buy curtains (L, K) - Figure out how Rohans TV is going to be placed / Rohan - Shoot the Macbook disassembly video / Juho, Markku	**- Outline presentation (all)** **- Compile pres. Deck** - Design EXPE signs (for the explosion view tower, proto, etc) / Linda - Design the handouts, stickers etc. / Chongbei, Linda, Kirsten?? - Order handouts (K) (-> you guys can hopefully get the eBay reimbursed, in case we're out of money)	- Presentation deck/script - FAQs done - EXPE booth layout - Handout design - Signs/posters? - Videos figured out - Design specs! **- Polish prototype**	**- Presentation outline and slides DONE** - Rehearse presentation - Finishing	**- Rehearse presentation** - Finishing	- Set up booth: tables, chairs, cords - Rehearse presentation **- Pick up final prototypes** - Assembly - Finishing - Take photos	**EXPE!** **EXPE!**

Table 13 *Final two-week timeline*

6.3 Project Budget

6.3.1 Helsinki Budget

Item	For what	Cost	Purchaser	Date	Vendor
Screwdrivers etc.	Final	6.52	Juho	4/28/2010	Home Depot
Digital Caliper	Final	39.9	Juho	4/28/10	ACE
Tape, aluminium, rope, o-rings	Final	52.99	Juho	5/28/10	Home Depot
Stereo mini plugs, gearhead, a&d ad	Final	23.73	Juho	5/5/10	Fry's
SLA Printing	Final	2800	Linda	6/1/10	Prototype Plus
Art Supplies for paper prototyping	Final	30	Linda	5/18/10	Art Store University Avenue
EXPE t-shirts	Expe	250.39	Linda	5/29/10	Zazzle
EXPE stand	Expe	146.38	Linda	5/29/10	IKEA
Mac	Final	1100	Design Factory	6/2/10	Apple Store
Expe brochures	Expe	82.6	Linda	6/3/10	Kinkos

Table 14 *Helsinki spring budget*

6.3.2 Stanford Budget

Funds (without rollover):	$5,000.00	Aaron
Funds Spent:	$5,785.64	Rohan
Funds Available:	-$785.64	Kirstin

Item #	Date	Item Type	Vendor	Description	Cost	Funds Available
1	4/1/2010	Food	Rincon Sabroso	SUDS	$300.00	$4,700.00
2	4/2/2010	Mileage	-	Autodesk Meeting in SF (80 miles)	$40.40	$4,659.60
3	4/5/2010	Wireless Keyboard	Amazon.com	X is finished proto	$82.84	$4,576.76
4	4/10/2010	Green LED Rope	Fry's	Space Decoration	$10.90	$4,565.86
5	4/10/2010	Ear Buds	Fry's	X is finished	$29.99	$4,535.87
6	4/10/2010	Tax	Fry's	Tax	$3.78	$4,532.09
7	4/10/2010	1/4 pipe grip	Home Depot	X is finished proto	$0.69	$4,531.40
8	4/10/2010	7/16 pipe grip	Home Depot	X is finished proto	$1.29	$4,530.11
9	4/10/2010	3/4 PVC pipe	Home Depot	X is finished proto	$1.52	$4,528.59
10	4/10/2010	PEX pipe	Home Depot	X is finished proto	$1.70	$4,526.89
11	4/10/2010	PEX pipe	Home Depot	X is finished proto	$1.78	$4,525.11
12	4/10/2010	hinge snapper	Home Depot	X is finished proto	$2.99	$4,522.12
13	4/10/2010	Tax	Home Depot	X is finished proto	$0.92	$4,521.20
14	4/10/2010	Friction hinge	Ace Hardware	X is finished proto	$5.99	$4,515.21
15	4/10/2010	Tax	Ace Hardware	X is finished proto	$0.55	$4,514.66
16	4/21/2010	FDM Prototype	Stanford PRL	X is finished proto	$90.00	$4,424.66

17	4/27/2010	HP Laptop	Best Buy	Laptop	$630.71	$3,793.95
18	4/27/2010	HP Laptop (Returned)	Best Buy	Laptop	$85.50	$3,708.45
19	4/27/2010	Cab Fare	SF Cab Ride	Cab Ride to Lunar Design	$11.00	$3,697.45
20	4/19/2010	Acrylic and Plastics for Prototyping	Tap Plastics	Various plastics for prototyping	$65.66	$3,631.79
21	5/5/2010	Macbook Unibody	ebay	Final deliverable	$700.00	$2,931.79
22	5/5/2010	Macbook Alumnium	ebay	Final Deliverable	$740.00	$2,191.79
23	5/11/2010	Adesso Keyboard	Newegg	Final Deliverable	$79.99	$2,111.80
24	5/11/2010	Adesso Keyboard	Newegg	Final Deliverable	$79.99	$2,031.81
25	5/11/2010	Tax	Newegg	Final Deliverable	$13.20	$2,018.61
26	5/11/2010	Shipping & Handling	Newegg	Final Deliverable	$40.41	$1,978.20
27	5/12/2010	Screw Hex Nut	McMaster-Carr	Final Deliverable	$3.98	$1,974.22
28	5/12/2010	Screw Hex Nut	McMaster-Carr	Final Deliverable	$3.98	$1,970.24
29	5/12/2010	Disc Spring	McMaster-Carr	Final Deliverable	$21.28	$1,948.96
30	5/12/2010	Tax	McMaster-Carr	Final Deliverable	$2.71	$1,946.25
31	5/12/2010	Shipping	McMaster-Carr	Final Deliverable	$4.50	$1,941.75
32	5/12/2010	Digital Caliper	Home Depot	For CADing	$38.19	$1,903.56
33	5/20/2010	SLA Laptop Case	Prototypes Plus	Final Deliverable	$2,025.00	-$121.44
34	5/4/2010	Cooling Fan	Performa	Final Deliverable	$7.62	-$129.06
35	5/4/2010	LCD Cable	Performa	Final Deliverable	$22.87	-$151.93
36	5/4/2010	LCD Cable	Performa	Final Deliverable	$15.25	-$167.18
37	5/4/2010	LCD Cable	Performa	Final Deliverable	$15.25	-$182.43
38	5/4/2010	Shipping	Performa	Final Deliverable	$27.38	-$209.81
39	5/26/2010	PVC Pipes (x18)	Home Depot	EXPE Booth	$27.00	-$236.81
40	5/26/2010	PVC Joints (x15)	Home Depot	EXPE Booth	$5.10	-$241.91
41	5/26/2010	Acrylic Sheets (x10)	Home Depot	EXPE Booth	$32.90	-$274.81
42	5/26/2010	Pine Rounds (x2)	Home Depot	EXPE Booth	$33.96	-$308.77
43	5/26/2010	Tax	Home Depot	EXPE Booth	$9.15	-$317.92
44	4/2/2010	Parking	Port of SF Parking	Autodesk meeting in SF	$12.00	-$329.92
45	4/27/2010	Mileage	-	Autodesk meeting in SF (80 miles)	40.4	-$370.32
46	4/27/2010	Parking	Port of SF Parking	Autodesk meeting in SF	$12.00	-$382.32
47	5/30/2010	Sand paper 120	ACE Hardware	Final Deliverable	$5.99	-$388.31
48	5/30/2010	Sand paper 220	ACE Hardware	Final Deliverable	$5.99	-$394.30
49	5/30/2010	Sand paper 320	ACE Hardware	Final Deliverable	$5.99	-$400.29
50	5/30/2010	Tax	ACE Hardware	Final Deliverable	$1.66	-$401.95
51	5/30/2010	Spraypaint plastic primer	ACE Hardware	Final Deliverable	$7.99	-$409.94
52	5/30/2010	Super glue Loctite	ACE Hardware	Final Deliverable	$4.49	-$414.43
53	5/30/2010	Super glue Quiktite	ACE Hardware	Final Deliverable	$4.49	-$418.92

54	5/30/2010	Glue plastic welder	ACE Hardware	Final Deliverable	$5.49	-$424.41
55	5/30/2010	Tax	ACE Hardware	Final Deliverable	$2.08	-$426.49
56	5/26/2010	Mileage	-	Drive to Home Depot (10.2 miles)	$5.10	-$431.59
57	5/28/2010	Mileage	-	Drive to Home Depot (10.2 miles)	$5.10	-$436.69
	5/29/2010	Mileage	-	Drive to IKEA (10.2 miles)	$5.10	-$441.79
59	4/19/2010	Mileage	-	Drive to TAP Plastics (13 miles)	$6.50	-$448.29
60	6/1/2010	Spray paint primer	Ace Hardware	Final Deliverable	$7.99	-$456.28
61	6/1/2010	Tax	Ace Hardware	Final Deliverable	$0.74	-$457.02
62	6/1/2010	Spray Paint Aluminum (x2)	Home Depot	Final Deliverable	$5.96	-$462.98
63	6/1/2010	Tax	Home Depot	Final Deliverable	$0.55	-$463.53
64	6/1/2010	Acrylic sheet	TAP Plastics	Final Deliverable	$12.02	-$475.55
65	4/19/2010	Mileage	-	Drive to TAP Plastics (13 miles)	$6.50	-$482.05
66	5/31/2010	EXPE Poster	FedEx Office	EXPE	$128.49	-$610.54
67	6/2/2010	Materials for EXPE	Fry's Electronics	EXPE	$116.79	-$727.33
68	6/2/2010	Nestle Paper	CVS Pharmacy	Final Prototype	$6.99	-$734.32
69	6/2/2010	Avery Marker	CVS Pharmacy	Final Prototype	$8.29	-$742.61
70	6/2/2010	Pencil Pack	CVS Pharmacy	Final Prototype	$3.99	-$746.60
71	6/2/2010	Poly Divider	CVS Pharmacy	Final Prototype	$2.79	-$749.39
72	6/2/2010	Sharpie Marker	CVS Pharmacy	Final Prototype	$3.79	-$753.18
73	6/2/2010	Elastic Bands (6ct)	CVS Pharmacy	Final Prototype	$4.99	-$758.17
74	6/2/2010	Tax	CVS Pharmacy	Final Prototype	$2.21	-$760.38
75	6/2/2010	Fasteners	Ace Hardware	Final Prototype	$1.50	-$761.88
76	6/2/2010	Fasteners	Ace Hardware	Final Prototype	$1.62	-$763.50
77	6/2/2010	Fasteners	Ace Hardware	Final Prototype	$1.20	-$764.70
78	6/2/2010	Fasteners	Ace Hardware	Final Prototype	$1.62	-$766.32
79	6/2/2010	Fasteners	Ace Hardware	Final Prototype	$1.50	-$767.82
80	6/2/2010	Fasteners	Ace Hardware	Final Prototype	$1.20	-$769.02
81	6/2/2010	Sheet Aluminum	Ace Hardware	Final Prototype	$7.99	-$777.01
82	6/2/2010	PC Epoxy	Ace Hardware	Final Prototype	$6.49	-$783.50
83	6/2/2010	Tax	Ace Hardware	Final Prototype	$2.14	-$785.64

Table 15 *Stanford spring budget*

6.4 Process Reflection

6.4.1 Communication Tools

The Autodesk team utilized several different communication and collaboration tools throughout the project.

Communication Tools	
Tool	**What is was used for**
E-mail	Asking questions, scheduling conference calls. Laptop specific links were shared on one thread.
G-chat	Quick team member updates/questions.
Dropbox	Sharing and collaborating on larger files (photos, videos, documents). Google Docs also utilized a couple of times.
Skype	Conference calls for brainstorming, to discuss team planning, and to collaborate on larger documents
ME 310 Wiki	Uploading documentation, checking out deadlines
GoTo Meetings	Conference calls with Autodesk liaisons

Table 16 *Communication Tools*

Dropbox became the primary tool for file sharing because it provides the simplest user interface – the ME 310 Wiki is difficult to update and edit and so became less and less used as winter quarter progressed. However, especially during hectic documentation editing Dropbox became too slow and it was too easy to miss each others edits. Team members used the different tools in very different ways: for instance sharing weekly plans in Dropbox was very efficient for some, but others never visited the document.

The two student teams held Skype video conferences one to two times per week to exchange progress updates and discuss next steps in the design development. Real-time file sharing is difficult to do using Skype, but the teams got by using email and screen-sharing to collaborate during their video conferences (Figure 96). The main problem the teams encountered with video conferencing was the inability to join the conference from multiple locations. The student teams tried using GoTo Meetings for conference calls with Autodesk liaisons (who were in different locations), but encountered many problems with this tool (e.g. feedback, echoing, indistinguishable voices, dropped calls, etc.).

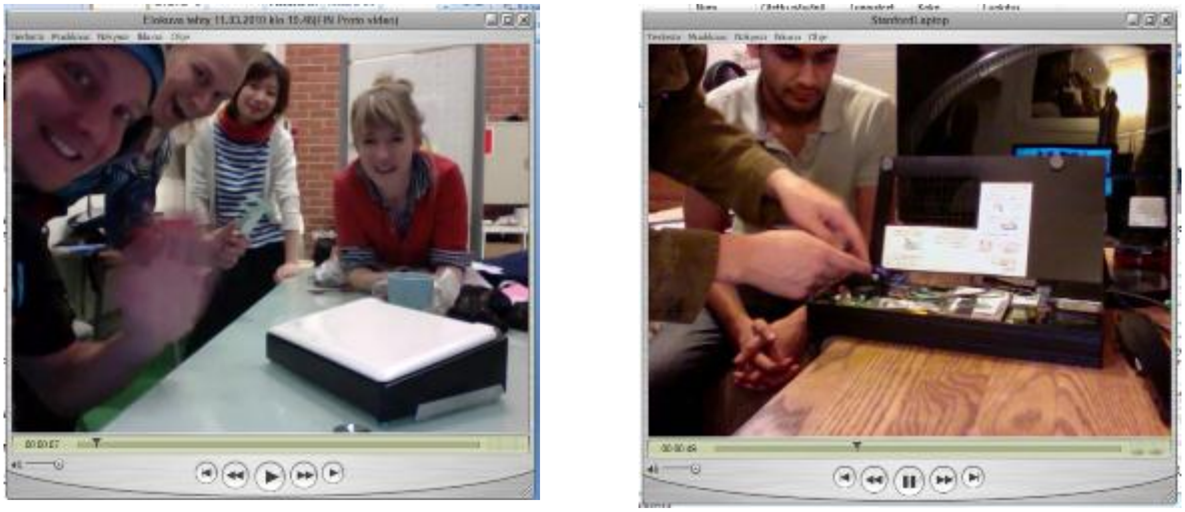

Figure 96 *Teams demonstrating prototypes via Skype video*

For the laptop prototypes, the two subteams made videos to demonstrate their prototypes to each other. This was a very efficient way to express ideas. Showing concrete things in Skype, even if the resolution wasn't that high, was always better than just talking. This was something that was stressed a lot by the TTeam in relation to SGMs, but not in intra-team communications.

Figure 97 *Juho demonstrating PCB removal via Skype*

Another thing that was hard for the team throughout the year was making decisions. Discussions via Skype became easily misguided and at times didn't have any rational logic behind them. Also, at times the time difference made one half of the team push decisions through in unintentional ways, when the other half of the team was struggling to stay awake. In order to reason decisions and find objective metrics for decision-making, the team tried to collaborate on PEW charts and feature-lists. If the design team encounters a deadlock of opinions and could not move forward, an objective third party should have been brought in to mediate as soon as possible.

Communication lessons learned

- Always begin meetings with a focus/agenda in mind, and stick to it! Approximate breakdowns of time spent per point are helpful.
- Delegating tasks to specific people is crucial – assign responsibilities to help get things done on time.
- Having a fixed meeting time and sticking to it would have probably been more convenient than always arranging new ones. On the other hand not everyone in the team needs to be present in all the meetings.
- Another way to help understand each other's design processes better was to have an all-night prototyping workshop via Skype with the both halves of the team present.
- Sharing information intra-team. At some point even local teams became dispersed as some of the prototypes were very technical in nature. Weekly summaries of group activities using a "newsletter" type of pinpointing. Team should have continued to talk about individual strengths/weaknesses and project goals.
- With all the team members in the same place, the team found it still hard to keep up the flow of communication. Working in the loft was efficient for the prototyping team, but not that easy for the documentation/EXPE/materials division.

6.4.2 Personal Reflections

Rohan Bhobe

The aspect of this project that surprised me the most this quarter was just how inefficient global collaboration can be when teammates are scattered in different places. As a team, we began to have much more productive Skype chats towards the end of winter quarter, but once we were all able to gather together in the same place, our working habits became much more streamlined. There is a big cost to "working remotely", but I never realized it until we all came together!

Although our team spent a lot of time trying to plan ahead, we still had trouble sticking to schedule. Towards the end of the project, skipping one day of work would mean that a significant percentage of the remaining time was gone. This realization didn't hit me until we had about three weeks left in the quarter. Luckily, I think this dawned on our team just in time, as we managed to get our final prototype parts back and finish the product about 45 minutes before EXPE!

All in all, I have learned more in ME310 than I can put in words. I realize the importance of always having a plan B, having a solid agenda and sticking to it, and not getting so bogged down in the details that the bigger picture is missed. I now know what it's like to collaborate globally over an extended period of time, submit a prototyping job to a vendor, and researching/designing for someone that is not myself. It's been one hell of a ride, and I can confidently say that I leave ME310 better equipped to design products that can satisfy the needs of my users!

Aaron Engel-Hall

This course has been nothing short of a 'wild-ride.' As an undergraduate I studied physics – and as a physics major I took courses on everything from statistical mechanics to quantum mechanics to advanced low-temperature physics. But I can easily say that I learned more in this class than any other class I've ever taken. As I expected, I learned many Mechanical Engineering oriented skills such as CADing, the LaserCAMM, the Lathe, FDM, and Milling. And with such an in-depth project I learned an incredible amount about what it truly means to build a "green" product. However this was only a small portion of the lessons that 310 had to offer. Most shocking, and most valuable, were the less tangible lessons I learned about working on a team. The challenges that are presented by different cultures, timezones, personalities, working styles, and personal preferences; and the solutions, compromises and arguments that arise were unexpected – to say the least. I wish I could launch into all that I learned about working on a team, but that would probably add another 50 pages to this document.

Although this will sound sappy (and it is sappy, but sappiness suddenly becomes appropriate towards the end of the year when everyone is set to go their separate ways) I valued the people in 310 above all else. Not only did I really like my teammates (of course some of them were difficult to work with – but liking someone and working well with them are totally different things) but I genuinely respected the intelligence and hard work of everyone in the class. 310 definitely becomes an overwhelming pressure in your life – but its bearable because the projects are so fascinating and the people so fun that you never seem to mind the frequent all-nighters.

I want to take this last chance to thank everyone in the class; from the students to the professors to the TA's for everything they've done. And of course - Thanks for EXPE!! That was an amazing day – something I will never forget.

Kirstin Gail

Wow. I can't believe how much I learned from this project. First and foremost I learned how to work with and communicate with a pretty diverse group of people, each of which has unique working styles. At first I found it incredibly frustrating to deal with team members' tardiness, unwillingness to make compromises, and different work schedule. After getting to know my teammates better and having some team dynamics discussions, we figured out how to make it work. I feel very lucky to have gotten to know such fun and interesting people.

As far as the design process goes, I also learned quite a bit. Never before have I had to collaborate on such an open-ended, long-term project. "Embracing the ambiguity" was often difficult and almost irritating, but overall a very good learning experience. I wish that the team had taken more advantage of outside resources, as there are numerous experts in the consumer electronics and sustainable design fields in the Bay Area. The Helsinki students seemed to know how to take advantage of such resources, but the Stanford team members (having learned during undergrad how to teach themselves), relied more on their own abilities than on outside resources. Now I know for next time!

Despite all the satisfying ups and embarrassing downs that this project brought, I am glad to have taken the course – I would not be where I am today without it.

Juho Huotari

In the beginning the paper bike design section was really helpful to get know the team. It could have been even better if we would have done it together with whole global team. I liked the design process idea of keeping the doors open for all new ideas until the very end of the process. Still the time usage in the fall and winter quarter should have been more effective. The course taught me a lot in international communication via Internet. I have taken courses where we used only Internet to communicate but never this big/long. I couldn't imagine that communication will take this much time and energy and how complicated it is to use just to show and demonstrate ideas. I learned that there should be meetings at least few times per week even though there wouldn't be any special deadline coming, just for keeping the team dynamics up. And one big thing I understood was that it is really easy to skip problems for example in team dynamics when working via internet. Other thing when working for a long time just using the Internet for communications between the team was that if there aren't weekly meetings the teams shared goals might not be aligned anymore. And for that those weekly meetings could be very beneficial. Maybe the most important thing I learned was that if there is a possibility for the whole team to be in one place at the same time, it's really important that everyone could join.

Something I learned from the meetings was that there should be clear agenda for every meeting that you can read through before the meeting and prepare for that. Because of the time difference if you forget to say something it could take 1-2 days to get contact again. Overall the course was full of small things I learned. We ran in many problems and new situation and I think in next project it is easier to foresee problems and prepare for them.

Markku Koskela

The course started with building the paper bike, where we had our first difficulties as a team that we managed to overcome later. I think the paper bike exercise was a success for me as a whole and I was extremely proud of our creation, the Humanwheel.

I felt that it was good to have our first team 'crisis' already in the paper bike, because I think it made our team stronger and we were able to figure out personal strengths and suitable roles for everyone easier during the actual project.

I feel that our project didn't quite find it's way during the first half, and we just went here and there with our prototypes trying different things. We did learn a lot all the time, but couldn't quite focus enough since we didn't have a clear picture what product we were designing. I think a more exact design brief, or just earlier decisions would have allowed us to focus more on the product from the beginning and the end product could have been totally amazing, instead of the good what it was.

Working on both sides of the Atlantic proved to be harder than I originally thought. I knew from previous projects that good communication is the key to a successful project, but as hard as we tried, communicating solely via email and Skype wasn't quite enough. It was often hard to find a common point of view and understanding between Stanford and Finland. The difference was evident when the Americans came to Finland in February and we found common ground and got the project leaping forward.

The most important thing I think I've learned during this course was working with totally different types of people and overcoming difficulties. I also learned a lot about working under extreme pressure and really tight schedule.

Finally I would like to Thank you my friends for making this course an amazing experience while creating a successful product.

Linda Liukas

I wrote my master's thesis on communicating corporate social responsibility and found the subject to be very vague and conversational. This course proved that at least green product design is far from that.

During the year, I discovered that I'm not that much of a *product* driven person, more process or service driven. I found it far easier to work the closer we were to the final product and the more set the different features were. On the other hand, I could just admire the focus and effort my team mates could put into the tiniest details of the product. Occasionally seeing the world through their eyes was very refreshing. Also, should the business side be implemented only in the end of the product, the results would probably be catastrophic. In future projects, I know to involve myself in the product design even though it would be outside my comfort zone.

One of the overarching themes for me during this course was building trust between people with different academic backgrounds. If you don't understand the least bit about 3D cadding or soldering or joint types how can you evaluate how much time it is going to take or what should be done with it? You don't - sometimes you just need to trust in the other persons professionalism blindly. And how to build this trust among people that barely know each other? Also, as an economics student, I sometimes felt a little alone. The designers and engineers had the product in common, they had something concrete to discuss. Thinking back I probably made too little effort in including the rest of team members to the "other sphere" of the product.

Another theme that constantly came up was sharing the same vocabulary. For us, different words have a very different meaning and we don't understand the same connotations and background. This became very true with words such as modularity, user centric design or even joint types. Far worse were green design specific words, which lacked often real-world examples. It took us surprisingly long to agree and reason the Green as a by product –thought.

I learned so many things I never anticipated learning, foremost about myself and my profession in relation to others. One of the fundamental things a business school student that I'll try to do is to think my education through a mindset focused on specific skills. How can I help? What do I actually know?

Chongbei Song

I have so many questions in the final stage of this project. The first question is why I want to take this course. The answer to this question was positive and childish when I reviewing the earlier motivation letter for ME310. I want to learn, apply, and experience the Design Innovation Process through a practical project. But how many of us have thought about the meaning of this process? I feel it's crucial to keep a holistic image of the process in mind; otherwise it's easy to fall into a self-centered working style.

I'm used to be an industrial designer and concept planner in a multi-disciplinary design team. It's the first time for me to work in an engineer dominated team. Communicate design knowledge and thinking is never easy. What can I do to keep my role in this team rather than end up with an unprofessional graphic designer? It takes long time to let the teammates know that the designer is not equal to artist; designer's job is not just giving a beautiful case to a product or aesthetic design. But, I feel still lack time and opportunity to present designer's capability. It was frustrated that the Human-Centered Design activities which I want to put many effort on are not valued in the whole process. User study and test are done with a bad grace, and user's feedbacks usually provide little guidance, for the reason of deficiency motivation and time shortage. I feel designer is a lonely job in this team. I'm wondering how I can truly qualify as T-shaped designer and communicate with engineers using a common language. How to encourage engineers to be empathetic to branch out into design or anthropology? Is it that difficult to ask all the team members to explore insights from many different perspectives and recognize patterns of behavior that point to a universal human need?

I'm disappointed of my performance in the Fuzzy Front End. The concept was decided in haste with less focus on exploring crazy ideas and human need, therefore lost the greatest opportunity for improvement of the overall innovation process. The design team's attention dramatically focused on the product development, this formal and structured process, in order to achieve the functionality efficiently. I was failed to convince the design team to take more time rethink the concept and take front-end activities to increase the value and success probability of high-profit entering product development and commercialization. That led to a messy situation in the last stage that our product has so many features that even submerged the main benefit. It was unwise to tackle with these unnecessary features in the very end by sacrificing user test and modification section. However, it is a good lesson for us to learn for the future project.

I have to say I learned a lot what I may not have chance to learn from a design school project. I realize that I should never lose passion to continue a project, because we never had a chance to start all over again.

7 Future Work

"People will buy it because it's cheaper. The green will be for free."

Vinod Khosla, SUN Microsystems

How do we envision the future of Bloom? The Autodesk team did not only design a greener product, but envisioned a more holistic approach on green design - one that can be extrapolated to a broader class of electronics.

As the team sees it, the business model of today for electronics creates artificially new, "un-green" needs. Technology becomes obsolete far quicker than many components get retired. On the other hand, having only one component breaking or malfunctioning, maybe worth $1, can ruin a laptop investment of $1000. The team believes that with the new kind of a laptop, an entirely new type of business plan is also necessary. Enter Bloom: the open source hardware laptop of the future.

This chapter outlines the vision regarding the future of Bloom from a business perspective, and then discusses the Autodesk's potential role in open source green design. The different insights that lead to the future business model for **Bloom** are described in Table 17.

Business-relevant lessons learned from prototypes	Where did we learn it from?
People aren't attached to the hardware. They love the stuff inside. Especially teenagers.	Functional Prototype
People are different. We will never get everyone to disassemble their consumer electronics. We have to design the recycling system around this.	Dark Horse Prototype
Technology becomes obsolete far quicker than many components get retired. A component breaking up, worth of $1 can ruin invaluable photos and a laptop investment of $1000. Warranty issues worry people.	CFP
Open hardware is a strong driver in designing greener electronics.	Functional Prototype
Logistics is a bulk business. The OEMs play a large role in the value chain. There are a lot of stakeholders during the lifecycle of a product.	Dark Horse Prototype
Owning the hardware is stupid: hardware breaks and gets outdated. Buying it upfront means investing a lot of money. Most companies lease their hardware – why not private people.	Purchasing various prototyping materials

Table 17 *Business-relevant lessons learned*

7.1 The Bloom Business Model

Bloom is leased to the user as a service, not a product.

Today, modular laptops might normally lead to a business model of profits from spare parts and not from service contracts. The Bloom business model, however, minimizes the total cost of ownership as well as extends the life of the laptop by offering a **subscription-based model** (Table 18, Figure 98).

Additionally, by involving the online open source community in the development process of the product, a two-level business model is established:

1) Customers who purchase the unsubsidized version have access to a self-service platform, namely the partner-hosted web communities. For these customers, self-reliance, upgradeability and do it-yourself is part of the value proposition. At absolute EOL, the customers can easily send the already separated components back to the manufacturer.

2) Customers in need of a continuously serviced laptop are willing to pay for a professional subscription. Since the disassembly process is so easy, salesclerks can help on-site, either by replacing components in the products, upgrading parts, or re-creating the products' whole look and feel with the customer.

	Unsubsidized	Premium
Pricing	$1200 (equivalent of a similar quality laptop)	$400 with a four year service plan (initial cost equivalent to COGS) Monthly fee: $20-$50 Total lifetime cost after four years: $420 (see appendix XX)
Warranty	1 year warranty	No outdating warrantey = no end of life. If something happens, the user can replace the component for free.
Upgrading	Possibility to purchase components	Discount price on new components
Support and administration	Web-based self-service and troubleshooting guides from a third party (e.g. iFixit)	Unlimited helpdesk support
Communications	-	Lifecycle-receipt; personalized recommendations on components. News updates.
Backup and online storage	-	Third-party assisted

Table 18 *Break-down of business model*

Figure 98 *Bloom business model*

Value Proposition for Bloom

It's a very small niche of customers who are interested in buying green. Most consumers purchase only if there is a direct consumer benefit. For these people, buying something "green" may make them feel good, but it should also come with other attributes, such as superior service, cost effectiveness or additional features.

For the customer, Bloom includes the benefits of easy repair and upgrade. Bloom has an additional functional benefit of a modular keyboard, where the keyboard and mouse can be lifted off of the casing to allow for a wider variety of use scenarios.

In addition, premium users are freed from the hassle of computer maintenance with the on-site physical stores and partner-driven internet communities helping them with the configuration, setup, data loss and repair. There is also a life-long warranty for the laptop – when something breaks, you either order the components or take it to the store and ask the salesclerk to upgrade it. Other partner-driven benefits could include a continuous back-up service in the "cloud" by a partnering cloud-computing company. Other services might include helpdesk and 3G bundles as well as software.

The third element of the value proposition, open source (OS), leaves consumers thinking more about what they can do to change things. The designers and engineers in the open source community can help by attempting to design generic systems in which new-technology components can be substituted for old one. Through the OS community, the customer is not buying into some benevolent story about how you should live a "green" life and what is considered good style. Other benefits could include

- Open source component and hardware design
- Public library for "Design for Repair"-solutions.
- Integrated add-ons, such as drawing table to make the computer more personal.

The manufacturer benefits by gaining customers through the subscription service, saving money on returned goods and component remanufacturing, and reducing assembly costs.

Pricing

Bloom will costs $400 up front with a four-year service plan (doubling the lifetime of a computer) and $1000 if customers would like to buy an unsubsidized version with no plan. The plan for premium customers costs 30-50 dollars a month, including an on-going warranty of four years. The average selling price of a laptop was $689 (http:/ / www. eweek. com/ c/ a/ Windows/ Netbooks-Are-Destroying-the-Laptop-Market-and-Microsoft-Needs-to-Act-Now-863307/). Consumers specify their laptop needs and pay a subscription rate accordingly, and can subsequently upgrade or downgrade equipment.

The monthly revenue stream reduces risk and provides payment in advance. Also, revenue streams from the recurring subscriptions are considerably greater than the revenue from simple one-time purchases. This way, the price will include designing not only for manufacturing cost, but also includes the costs (monetary and otherwise) for all the phases of the lifecycle, including manufacturing, deployment, maintenance, operation, and eventual retirement/disposal.

Customer Segments

The customers for an easily disassembled laptop can be found in both mature and emerging markets, especially in emerging markets the easy repair is a strong selling point, as the culture already supports this kind of activity (ref. Jan Chipchase..)

The Bloom model, with its specific modular features, is aimed at young people. From a business perspective, it's noteworthy that the paying customer is often the parent.

Customer Relationship with Bloom

By introducing a service model to the industry, all the partners in the ecosystem could benefit from strengthened customer relationships. Through the subscription and service model, individualized, personal, and local communication can be integrated in customer relationship management.

One example of this is a new kind of billing. Instead of getting a receipt with a "Macbook Pro", the customer would get a web-based nutrition list/birth certificate of Bloom. It would include a list of components and show transparently their prices. Also, utilizing Google Maps, the customer could see where the components derive from.

Key Activities

Because the laptop components are open source and they can be developed outside the hardware company, there is no relatively large budget needed for research and development. Key activities become OEMs product support services, product versioning, and testing as well as building the service platform around the product. This includes the store-chain wide education program for sales clerks and keeping the component logistics up-to-date. Bringing the products to be quickly repaired to the salesclerks at retail stores saves the company time and money.

Revenue Streams

The primary revenue stream is the subscription revenues from the customers. Additional sources of revenue include sales of components to external customers and the selling of unsubsidized laptops. The collected, working components can be resold and re-engineered for secondary markets. Only 10-20% of the product stream is normally involved in reuse, but it generates 80-90% of recycling revenue through reuse sales.

Cost structure

Cost structure involves the platform development and maintenance costs. To distribute the continuously serviced version, local branches are in place. This means sales and distribution costs are incurred.

Partner Network

First-priority partners are the laptop manufacturers and OEMs along with the open source community. Second-priority partners are the independent product and service designers, ecological organizations and DIY communities, such as iFixit, where the user can find help.

7.2 Future Directions: Autodesk & Bloom

During the design process, the team had many additional functional benefits and ideas to further develop with Bloom. Ideas concerned product packaging, optimizing the PCB integration, introducing a stronger user experience to the disassembly process, and generating additional swappable components. A number of outside stakeholders showed interest in our project. Hacker communities in Helsinki were particularly keen on the subject of open source hardware. They were the ones that initially suggested that the team should share its CAD files for the community to further develop.

Autodesk's role in the future of Bloom and other recyclable electronics could be to act as a hub between the OEMs (Original Equipment Manufacturers) and VARs (Value Added Retailers) as well as designers and the open source community. Keeping an up-to-date library of green, modular components and design choices across the different software offers the OEM/independent designers the possibility of making more compelling and ecological choices that are applicable across products ranges. Other ideas how to further use the

- **Open hardware** – share the laptop model and process description as a website under Creative Commons. Give the community tools and ideas to take the product further. Ask them to submit examples of new product ideas.
- **Generate ready-made CAD examples** and cases under creative commons license for Design for Reparability and Design for Upgradeability. Let the developers study and learn from these prototypes. Bring together open hardware design community of Arduino, Bugslab etc. people in the same spirit as iFixit has done for the DIY and repair crowd. Showcase other electronics recycling projects.
- **Product-bundling**: Advertise Ecotect Analysis tools.
- **Provide means to check compliance** with different legislation as well as green frameworks. At the moment the field is so vast and the requirements differ a lot. Extracting BOM data from the software would be incredibly useful.

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8.2 Vendors

1. Palo Alto Recycling Drop-off Center
   3201 East Bayshore Road
   Palo Alto, CA 94303
   Phone: (650) 496-5910

2. AT&T Wireless Store
   2805 El Camino Real
   Palo Alto, CA 94306
   Phone: (650) 617-8931

3. Fry’s Home Electronics
   340 Portage Avenue
   Palo Alto, CA 94306
   Phone: (650) 496-6000

4. Target Department Store
   4055 Fabian Way
   Palo Alto, CA 94303-4608
   Phone: (650) 812-8100

5. The Home Depot
   1781 East Bayshore Road
   East Palo Alto, CA 94303
   Phone: (650) 462-6800

6. K-Rauta Merituuli
   Isonniitynkuja 2
   02270 Espoo

7. Allen Steel
   505 East Bayshore Road, Redwood City
   (650) 369-2526

8.3 Human Resources

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