A Preliminary Framework and Case Studies for Product and Systems Design

by

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Abstract

Design processes and methods for product design are not as effective when products have a systems component. Products can have a systems component when they are within the context of a system, are a component of a system or are systems themselves. A review of relevant design processes and frameworks is followed by three case studies describing the design process of three products, one in each category mentioned above. These are: a solar powered assistance system for handlooms, a biogas generation system based on food waste from the city's waste stream and a virtual assistant and online platform for people with vision impairment in India.

Learnings from these projects are used to propose a preliminary framework for designing for products with a systems component. This framework proposes that the design process cannot be codified and must be approached depending on the use case. Research, concept generation, testing and post-product launch should involve research which considers the impacts of the product and system at large and small physical and temporal scales. The framework reframes the design process in terms of the design experience and capabilities of the designer. The designer constantly cycles between understanding the system and creating solutions through different parts of the design process.

The thesis defines the broadened role of the designer must be capable of abstract thinking, have subject matter expertise and possess technical and interpersonal skills, enabling them to take on a leadership role. It then suggests that further professionalization of the field of product and systems design is necessary given the rising complexity of socio-technological systems and suggests changes to the education system to cope with this. Lastly, it stresses that creativity and intuition are critical and the design framework sets the ground for creativity to generate great designs.

Thesis Supervisor:

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Chapter 1

Introduction

This thesis is an attempt at dissecting the requirements of designing in a complex world where products are not simple, standalone objects that interact with a user and do not have an impact beyond this sphere. Though it can be argued that this was never the case, it is more so in a world that's greatly interconnected and facing challenges such as environmental degradation, inequality and unsustainable sustenance systems. Not only are people more connected, objects are too. Socio-technological systems have become dominated by product focused enterprises rather than governments or local bodies. This has inadvertently provided a lot of power to a few organizations and consequently the people within these organizations that take these decisions.

'Unintended consequences' have become the go-to excuse for companies when their products cause problems. While this is understandable given the complexity of the products, it also unjustly relieves these organizations of responsibility. It can be argued that there are no such things as unintended consequences, there is only limited vision. This thesis aims to address issues with narrow and short-term views and decision-making.

Designing for multi-dimensional ideas such as sustainability and international development which require an understanding of various aspects and how they all move together requires complex thinking. Networked technologies like social networks and Internet of Things applications require thinking about the product that the user interacts with and also how multiple users interact with the broader system. Powerful technologies like Artificial Intelligence and their effect on realms like the workplace require careful examination and simulation of the way these tools will be developed.

A product is defined as a physical or virtual object or interface that a user interacts with directly and can be of varying degrees of complexity.
A system is defined as the interconnected parts that a product interacts with to better serve its purpose. The interconnectedness of systems makes them prone to behaving unpredictably, having externalities and propagating complexity.
This work focuses on products which interact with systems therefore raising the complexity of their own structure thus requiring complex thinking to achieve design goals and intended outcomes.

It is my view that current design processes are ill-equipped to address these major challenges. The most well-known process, the user-centered design process is designed to make it easier for non-designers to adopt design in their operations. It is simple and codified for easy application. It is useful when working on simple consumer products (which is what it was originally designed for) and represents a remarkable shift of focus to focus the design effort on the user of the product rather than the manufacturer but when it comes to working with complex systems (which it is beginning to be applied for, for example, healthcare systems, finance and business), it is grossly insufficient.

I focus on areas where traditional design processes seem to fail and work towards suggesting an approach that might be more successful. I study different product-system arrangements that reflect the current spread of products.

Product-system arrangements lie on a spectrum of different arrangements ranging from products that interact with systems to products that are system. These can broadly be categorized as follows:

1. **Products within the context of systems**

   This consists of products that exist within complex systems which interact with the product but may not be under the control of the designer. The designer must understand these conditions and design for them. The system typically consists of multiple stakeholders and various dimensions over which the design should satisfy working criteria for it to be an effective and useful design.

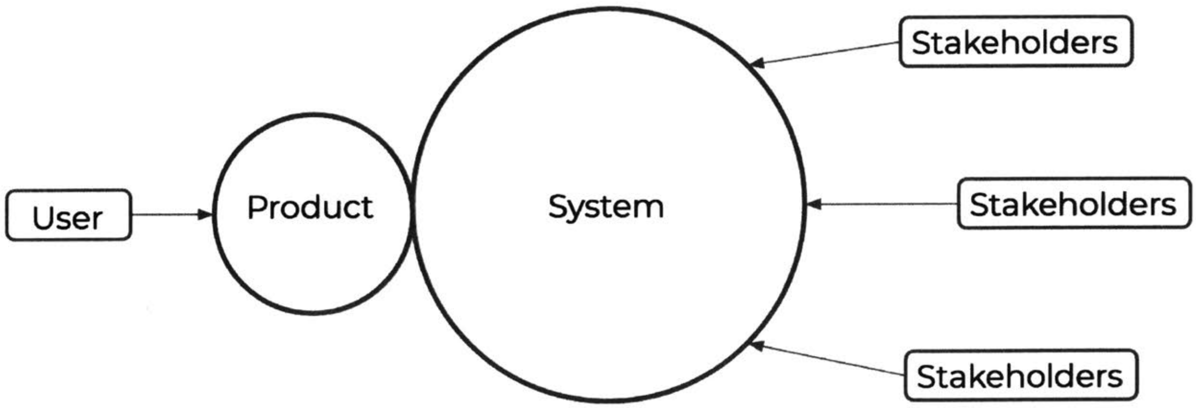

Figure 1: Illustration of products within the context of systems

Examples of this are products designed for sustainability which must consider various dimensions like sustainable sourcing, manufacturing and distribution, safe manufacturing practices, socially sustainable for employees, safe to use for users, reduced waste production, reduced carbon footprint, etc. A product must not only satisfy the criteria of being of use for the user but also meet all these additional criteria which are connected to systems outside the product which they may not have any say over.

Examples also include designing products such as healthcare products, energy products and agriculture products in the resource constrained international development context where the very nature of development must first be understood and then how the specific intervention performs in the context of where its used and for what periods of time must also be taken into account among various other contextual factors.

2. Products as components of a system

This consists of products that create systems, are created to fill gaps in a system or are created with a system. The designer therefore is more likely to have control over the system and a say in its design. The design goals of the product are influenced by the design goals of the system. The product may be a critical component of the system or be a minor part of it. The degree of overlap varies for different arrangements.

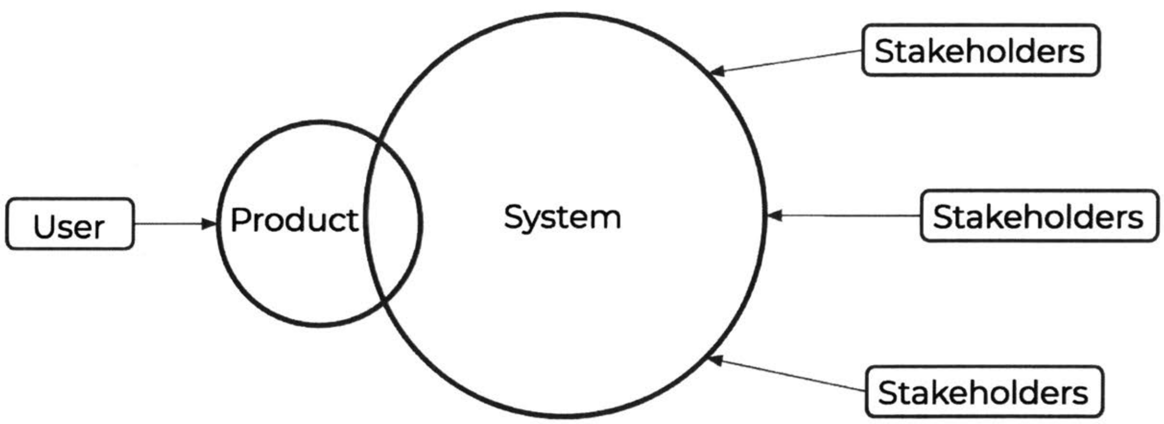

Figure 2: Illustration of products as components of a system

Examples of this include autonomous vehicles where the vehicle itself needs to be designed carefully with several considerations so that it satisfies the needs of the user but simultaneously, communication between autonomous vehicle has the potential to transform traffic flows, ownership models and even the structure of cities themselves.

Other examples are smartphone app marketplaces like the App Store and Play Store. The smartphones are the critical component and were designed to include more hardware than their first versions used regularly enabling them to become platforms over which other apps could be developed creating an entire marketplace and ecosystem.

3. **Products as systems**

This consists of products which are interfaces to systems. The user interacts with an interface which is the product. The interface uses the system to perform its functions. The designer has to design the entire system to be able to create the product.

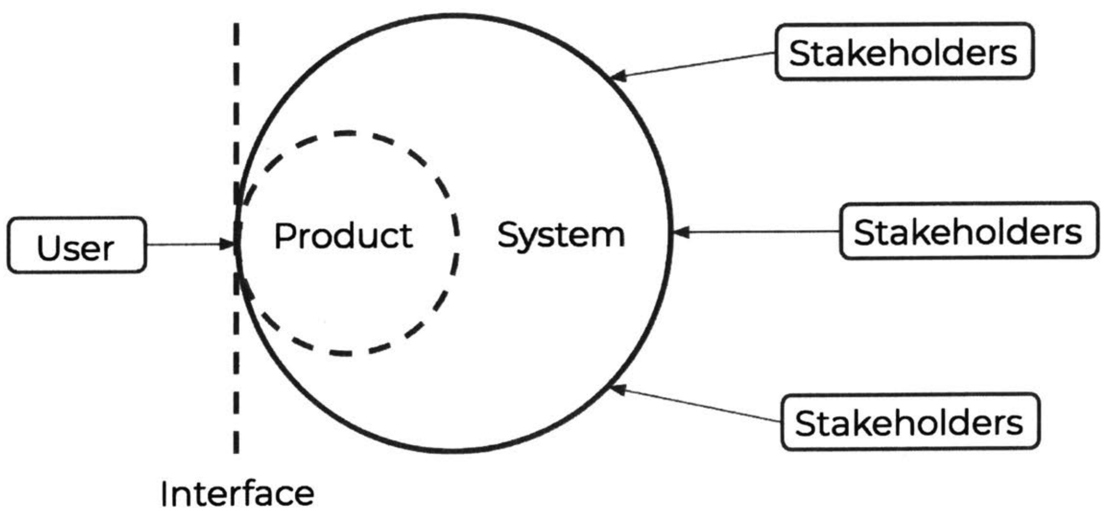

Figure 3: Illustration of products as systems

Examples include websites like Google where the interface is the search page and the system consists of the complex data processing, algorithms, advertising, etc. that make the search results possible. Another example is Facebook where the product is the user's Facebook feed and the system consists of all the other users, their activity, insights from their data, advertisers, etc.

Further examples are newer computing interfaces such as Artificial Intelligence based assistants where the interface may be voice or text or sight but the system behind the AI assistant is the real product. Applications of AI in the workplace also exist in this category.

There is scope for overlap between these different categories since a system may as well be a system of systems where different sub-systems fall into different categories. These categories may be nested or in parallel in different cases. For example, a product may encapsulate a system of more than one complex systems such as Amazon encapsulates the complex world of trade and commerce but is itself a complex system designed to make that possible.

I address these categories by describing in detail the design process and outcomes of three projects, one in each category.

The first case study is of the design and development of a product for use in the manual weaving industry (handloom) in India. It relies heavily on the context of handlooms as a dying industry protected by policy and NGO support with clear traditional methods and sensibilities.

The second case study is of the design and development of a household energy generation system that utilizes the food waste from the city's waste stream to convert it into biogas which can be used for cooking or to generate electricity.

The third case study describes the design and development of a virtual assistant for people with vision impairment which relies on an underlying platform for efficient product, information and service delivery in the existing infrastructure in India.

Since the projects described include proprietary work, final designs have not been described in detail and instead the focus has been on the design process for each case.

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Chapter 2

Literature Review

There exists a large body of literature devoted to design processes and methodologies applied to different domains. I focus firstly on processes that are known to be widely used and then on some insights from processes that I found relevant and insightful for the purpose of this thesis. I limit the study to processes defined for either products or complex systems to look for where they may intersect and the ideas that can be learnt from and built upon.

2.1 Design Thinking

The process taught in design schools worldwide whose many slight variants all fall under the bucket of 'Design Thinking' has become synonymous with the field of design itself. As a result, organizations that adopt it are able to label themselves as being design-conscious and design-driven. Design thinking is composed of several different ideas. It focuses both on the state of mind and the activities of the designer as they go through the design process. It arises out of research in creative thinking and problem solving.

Design thinking consists of the following steps, broadly in a chronological order:

1. Empathy
2. Problem Definition
3. Ideation
4. Prototyping
5. Testing

There are feedback loops between different parts of this process based on the findings. The perspective of the designer is also defined to be broad in the first step, focusing in by the second, broadening again in the third step and focusing in by the fourth.

This process has gained widespread popularity through the work of design firms such as IDEO and their role in education. The authors, David and Tom Kelley, have written about Design Thinking and are seen as leading voices in the field [1]. David Kelley is the most well-known design thinking academic (Stanford D-school) and a design practitioner (founder of IDEO). Another prominent author on the subject is the designer, Dev Patnaik, whose work focuses on user research [2].

Design thinking is a very effective tool for creative thinking and problem solving but falls short when dealing with complex systems because of its user-centric focus and simplified and codified process which does not lend well to solving large and complex problems.

2.2 NASA Systems Engineering "V-Model"

The V-Model is the process followed by NASA to design and launch their complex missions and operations. It follows a process shown below:

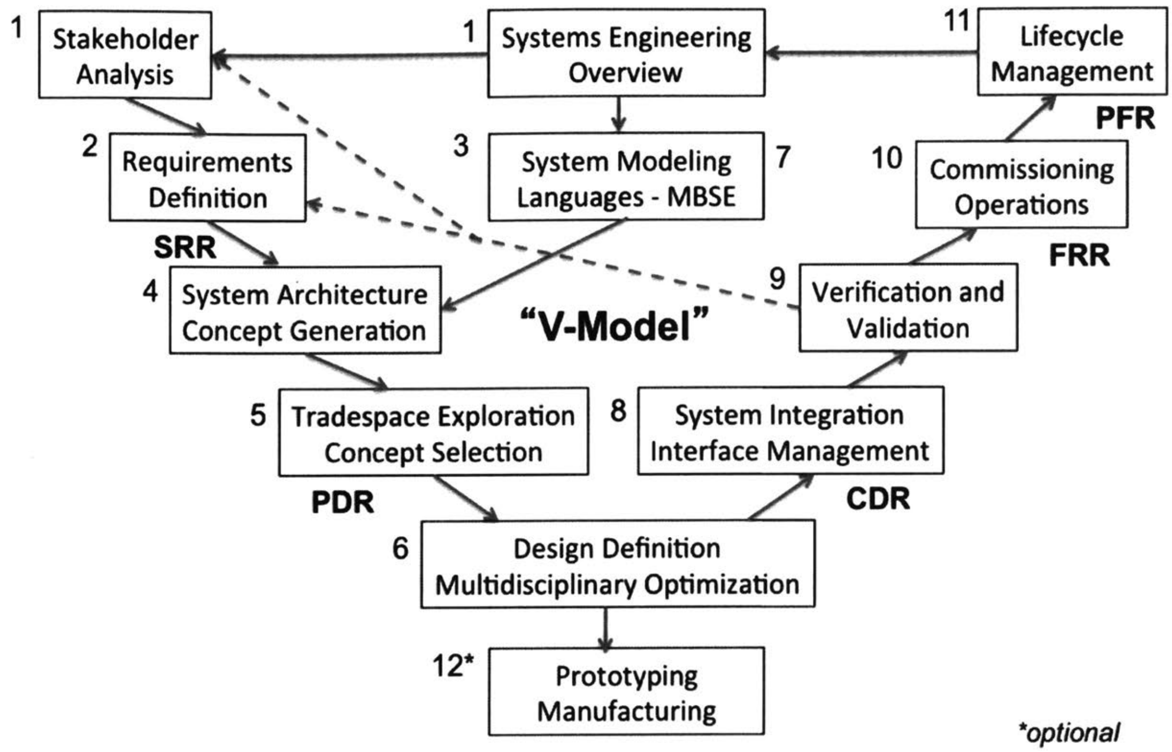

Figure 1: "V-Model" [3]

The process covers research, design conceptualization, testing, formulation and release. It is applied to complex systems such as aircrafts, rockets, space missions, etc. It has several checkpoints where decisions are analyzed and re-evaluated such as the SRR (Systems Requirement Review) for requirements definition, PDR (Preliminary Design Review) for concept evaluation, CDR (Critical Design Review) for selected concept evaluation, FRR (Flight Readiness Review) for final product evaluation and PFR (Post Flight Review) for post launch performance evaluation.

This process is designed for rigid systems with well-defined roles of components and sub-systems. Human parts of the systems are also expected to behave predictably and follow the roles assigned to them.

It is a rigorous and methodical process which is effective in designing for such systems but seems rigid when working on undefined problems and with unpredictable system components for example humans in social media products.

2.3 Axiomatic Design

The Axiomatic Design framework was developed by MIT Professor Nam Suh [5]. It consists of four concepts:

1. Domains – The customer domain, the functional domain, the physical domain and the process domain. Versions of the design process focus on the functional domain and physical domain only.

2. Hierarchies – The designer decomposes the problem by first attacking higher level problems to define functional requirements which are then broken down into lower level requirements. This is also done with design parameters.

3. Zig-zagging – Lower level requirements are dependent on the design parameter chosen for the higher level requirements. This process of pairing requirements and design parameters to generate further requirements and develop a concept is called zig-zagging.

4. Axioms – Axiomatic design consists of two design axioms namely the independence axiom which states that functional requirements must be uncoupled or decoupled from design parameters such that changing one design parameter does not also affect another part of the system and propagate complexity. The information axiom states that the simplest solution is the best solution and reducing complexity should be a

design a goal.

This process and the rules it lays down have axiomatically shown to be true by the authors research on various designs. The process is criticized for being retrospective rather than prescriptive. It is sometimes difficult to be creative within this framework while also keeping track of the various requirements and parameters and how they evolve. It can become difficult to codify a design within this framework.

That said, it is a very effective tool to evaluate designs and recognize problems and decompose them to solve them efficiently. It can be applied to a host of problem areas and is effective for systems design.

2.4 Systematic Engineering Design

This process was proposed by Gerhard Pahl and Wolfgang Beitz in their book "Theory of Systematic Engineering Design" [6].

Pahl and Beitz provide steps within broad phases that can be followed in the design process. These are as follows:

1. Requirements phase – This phase consists of all the steps required to understand the problem and define the product requirements and constraints. This includes business considerations and worthiness of the project for the designer.

2. Conceptual design phase – This phase consists of identification of the broad and abstract idea of the problem, organizing the problem into functions and sub-functions which define it more accurately, identify a broad solution area called solution principles from the available options, use the solution principles to generate concepts within this

scope, and evaluate these concepts on technical and business prowess.

3. Preliminary design phase – called the embodiment design phase where the concepts generated are defined definitively and evaluated to ensure that all the requirements are met and it is commercially and technically sound.

4. Detailed design phase – Realize the final design and document it in detail.

Notably, Pahl and Beitz write about how this method and all its steps are followed implicitly so it is better to be systematic about it. They do not however recommend that this method is applied automatically and leave its application to the discretion of the designer to judge based on their background and skills. They also stress the importance of creativity and intuition in the design process and state the designer must balance between being systematic and intuitive throughout the design process.

2.5 Product Design and Development

Karl Ulrich and Steve Eppinger's book [7] lays out a process for the design of products. This process is well defined with all the steps and everything that a step entails described in detail. The steps in the design process are as follows:

1. Opportunity Identification
2. Product Planning
3. Customer Needs Identification
4. Product Specifications
5. Concept Generation
6. Concept Selection
7. Concept Testing

8. Product Architecture

The process consistently keeps track of the design desirability, engineering feasibility and business viability of the concepts and the product. It also expands to include dimensions such as design for the environment and design for manufacturing which add additional constraints and requirements to the product. The process describes its applications in service design and product management as well. The process does not however venture into complex systems design or the nature of creative thinking and the qualities of a designer.

2.6 Design Methods

Design Methods by John Chris Jones [8] is perhaps the closest piece of literature that approaches the design of systems and products. The book talks about how it is necessary to look at products and systems both. It stresses on the importance of defining the purpose of design projects, and argues for functional and aesthetic harmony of products and systems with society. It stresses heavily on the role of creativity and intuition and also proposes design practice as a combination of technical and creative skills.

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Chapter 3

Case Study 1 – Solar Powered Assistance for Handlooms

(Product within the context of a system)

This case study describes the design process of a solar powered intervention for the manual weaving (handloom) industry. This required studying several considerations like cultural context, policy environment, market structure, supply and distribution networks, weavers' preferences, etc.

This makes it a good example of a product-system arrangement where the product is within the context of a complex system and needs to be designed in accordance with it.

3.1 Background

On this project, I worked at SELCO Foundation in their Bangalore office as a design intern during June and July 2017 and then remotely continued work on my project along with on-site employees since then. SELCO Foundation is a non-profit research organization based in Bangalore, India and affiliated with SELCO India, a solar power company. I was part of the Livelihoods Team that focuses on interventions using solar power that can provide livelihoods or improve upon existing means of livelihood. The work done here focuses entirely on low-income or marginalized populations such as manufacturing of yarn, fabrics, food, metal work, handicrafts and so on.

SELCO Foundation has several different teams and focus areas. These are illustrated in the figure below.

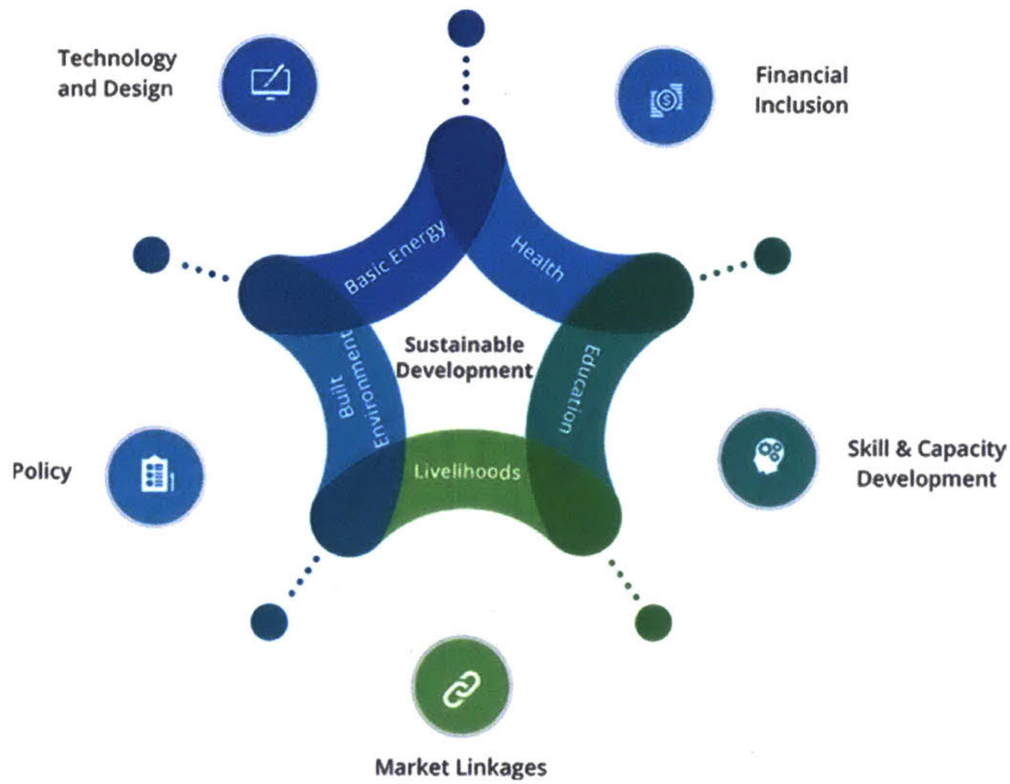

Figure 1: Structure of SELCO Foundation [1]

SELCO Foundation was a good place to work at for exploring products with a heavy contextual systems component because of their extensive work in technologies for sustainable development designed for the poorest of the poor which is a multi-dimensional field with many variables and ideas to be considered to design a useful, feasible and appropriate product.

3.2 The Handloom Industry in India

There are 2.37 million handlooms in India. 2.06 million of these looms are in rural areas and the remaining are in urban areas [2].

Of all these looms, 53% are used partially or fully for commercial purposes, the breakdown being 29% of all looms being used exclusively for commercial purposes and 24% used for a mix of commercial and domestic purposes. 38% of all looms are used exclusively for domestic production and 9% are idle [2].

Handloom production as a total share of cloth produced in India was 11% in 2016 and has been steady around that figure for the preceding 6 years [2].

There are 4.3 million handloom workers in India. 49% of handloom workers are aged 18-35, 21% are aged 36-45 and interestingly for the purposes of this project, 15% are in the 45-60 age range and 4% are over 60 [2].

The number of weavers has been declining steadily [2].

There are several types of loom in use in India like the frame loom, pit loom, loin loom and pedal loom which are of different sizes and used for different types of fabrics and weaves.

There is no uniform label or certification by any government agency or independent agencies that certifies a product as handwoven (or khadi which requires that the yarn was also hand-spun).

There are government entities involved in production, marketing and sale of handloom products. These agencies employ weavers and weaving workers to manufacture yarn and weave on site and also provide yarn to independent weavers who work for them. These products are then sold by these agencies. Buying from such an entity is one way of ensuring that the product you buy is genuinely handmade. Since this is a walled garden, it is protected from market forces. As a result, it also finds it difficult to compete with the market when it comes to designs and quality.

Apart from this, there are weavers' cooperatives who may also market their products directly. There are also vendors who operate in the market but have their products manufactured by independent weavers. This arrangement also typically involves the vendor providing the yarn and the weaver weaving it into the required design. Such vendors rely on their credibility to ensure that the product they sell is genuine.

There are also NGO's which employ people to manufacture khadi and handwoven cloth and market it. These work like social enterprises working at little or no profit.

The market is also flooded with lots of imitations and falsely labeled goods which are sold at a fraction of the cost of genuine handmade cloth but manufactured using powerlooms.

The government provides subsidies and credit lines and supports state-level agencies and weavers' cooperatives financially. This policy environment has ensured that this industry is still alive in India and at the scale it is at, though it has mostly died out in the rest of the world. Another factor is the demand for traditional designs and the value attributed to handwoven cloth both as a form of self-sufficiency made popular by Gandhi and as a mark of quality and tradition in garments with higher quality and design.

3.3 Glossary of Terms

Handloom: A manually operated loom.

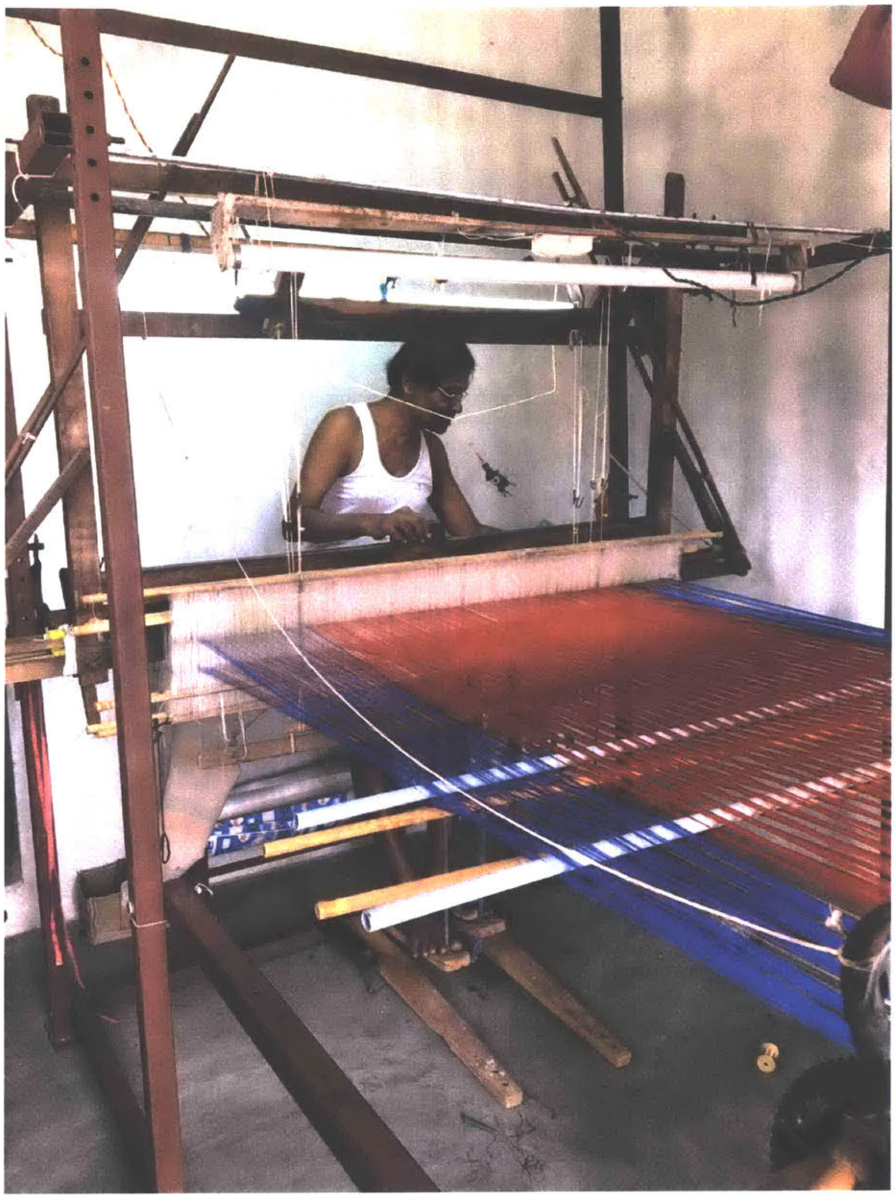

Figure 2: A handloom in the weaving village of Negamam, Tamil Nadu

Powerloom: A powered and mostly automated loom used in industrial production.

Warp: The vertical, fixed threads on the loom

Weft: The horizontal threads that are woven between the vertical threads.

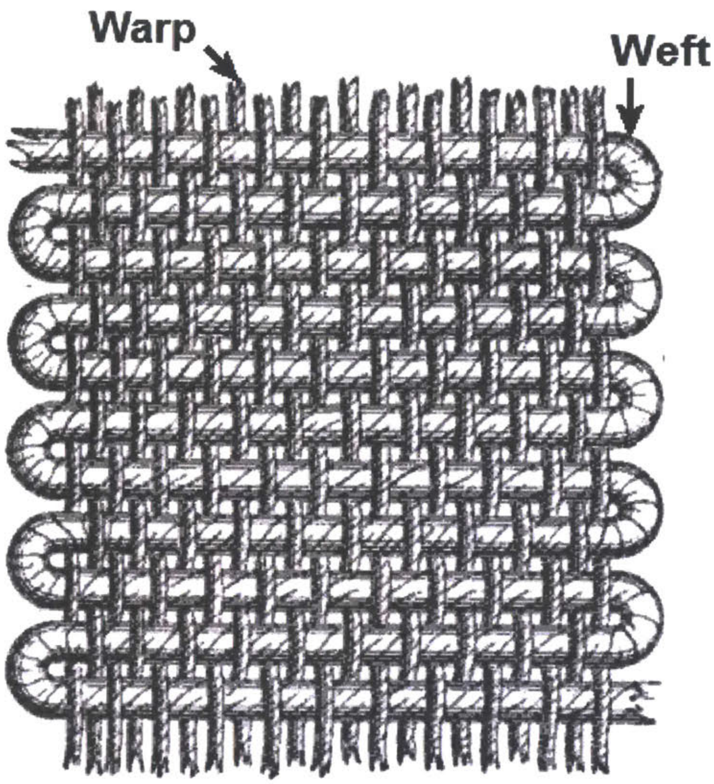

Figure 3: Warp and weft [3]

Picking:	The act of weaving the weft through the warp.
Shedding:	Raising and lowering of different warp threads to allow the warp to pass through.
Beating:	Tightening the warp thread into the woven part of the fabric so that the resulting fabric is tightly woven and not like a fishnet.
Reed:	The part of the loom containing a comb of threads used for beating.
Heddle:	An eye that the warp passes through used for shedding.
Treadle:	The pedals used to move a set of heddles.

Figure 4: Treadles

Shuttle: A wooden object with tapered ends which houses a spool of thread used for picking in handlooms.

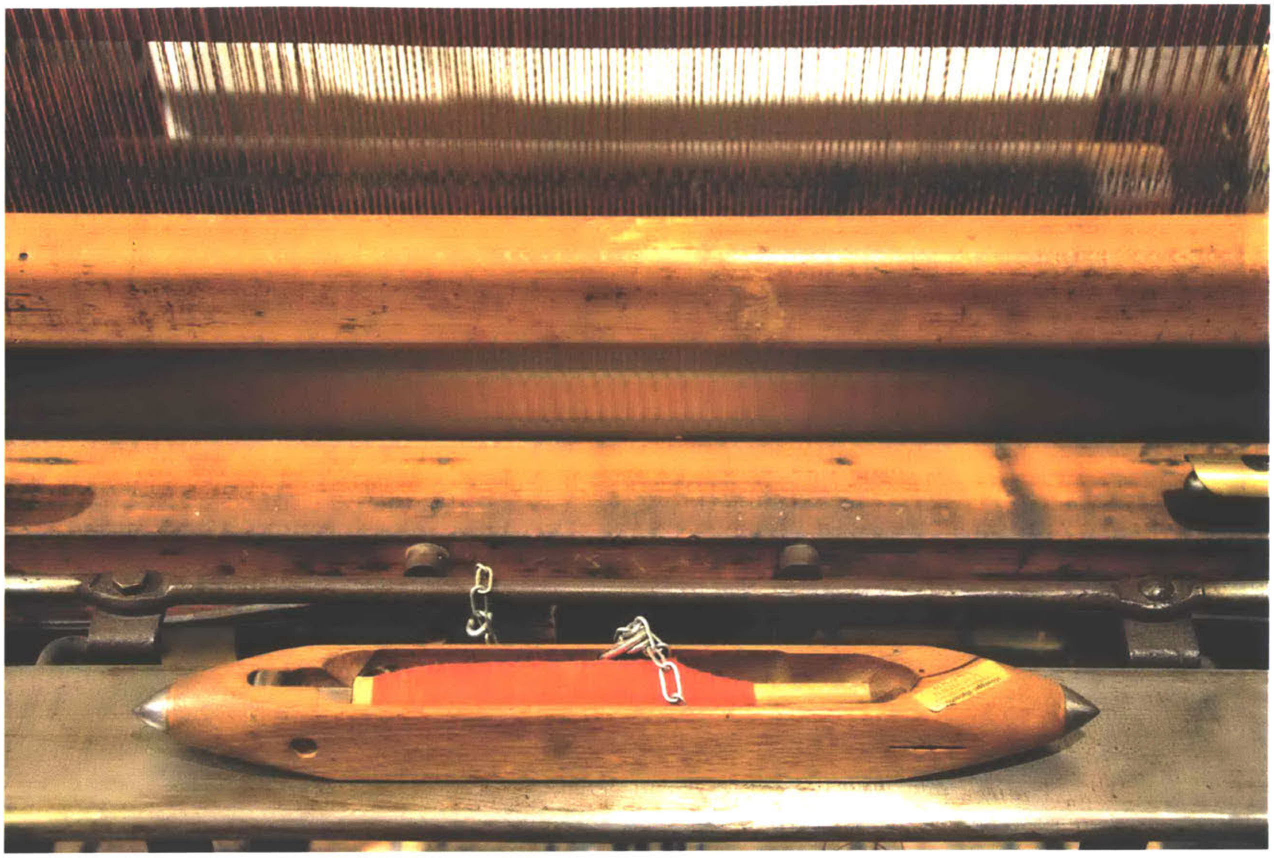

Figure 5: Shuttle [4]

Rapier: A faster picking method using two extendable arms used for picking in powerlooms.

Jacquard: A type of loom invented in 1804 which uses punch cards to lift and lower different warp threads to create any desirable pattern or type of weave.

Ppm: Picks per minute, the unit to measure the rate at which the weft is transferred through the warp.

Khadi: Handwoven cloth made exclusively from handspun yarn.

Figure 6: A Jacquard loom in the weaving village of Negamam, Tamil Nadu. Note the shedding mechanism atop the loom with punch cards.

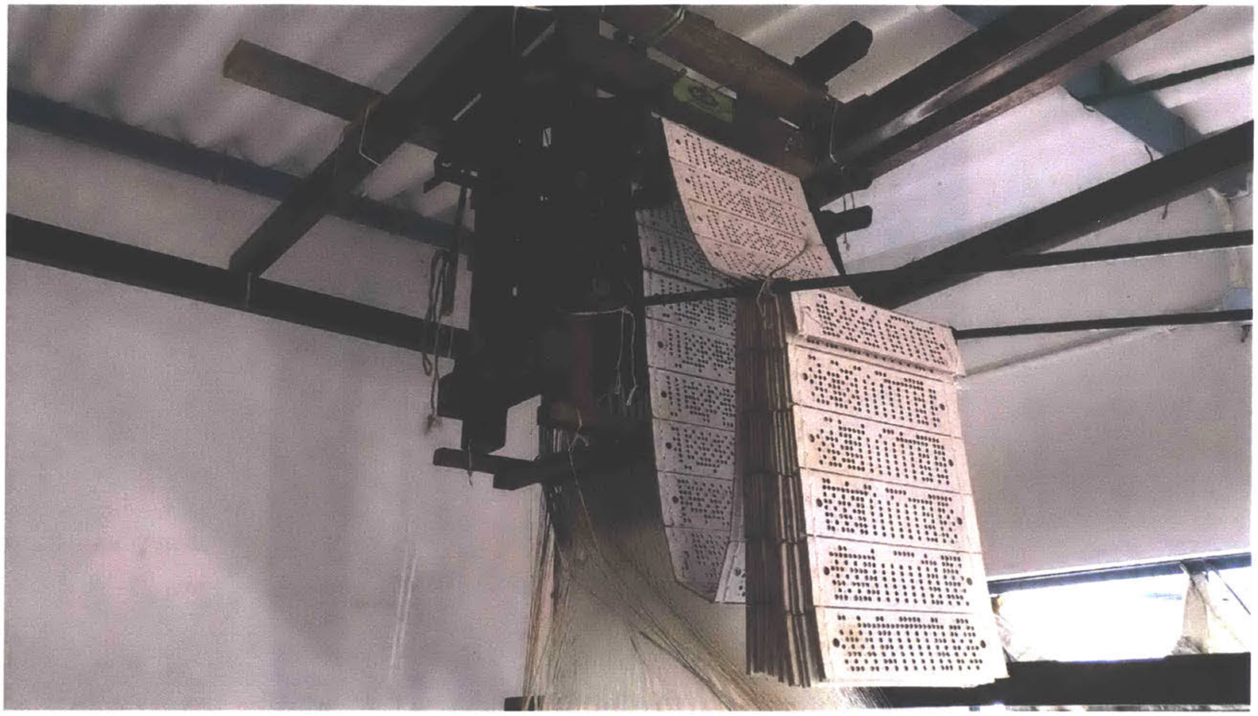

Figure 7: Close-up of punch cards and the jacquard unit

3.4 Existing Design

My brief was to study the manual weaving (handloom) sector and people involved in it in India and use my findings to help improve the design of a loom that was designed and manufactured by a partner company. The company was NRG Solutions based in New Delhi. They have designed a semi-automated loom. The company had identified three potential design intervention areas:

1. Increasing efficiency by reducing friction in the moving parts of the handloom.
2. Providing automation and coordination between the moving parts so that human error and skill required are reduced.

3. Increasing the speed of the different moving parts. The primary bottleneck here is the shuttle so one avenue for improvement was to study the possibility of equipping a handloom with a rapier mechanism [5].

The loom that NRG Solutions designed incorporated the first two points. The research involved for designing their loom was focused entirely on mechanical and production efficiency and speed. The primary goal was to raise the production capacity of handlooms so that they could, to some degree, compete with powerlooms. Since this loom was aimed ultimately for the weaver who owns and operates it, it can be argued that the loom was designed with the welfare of the weaver (user) in mind, which the designers felt would best be attained through increased production capabilities.

Figure 8: Sun Kharga, NRG Solutions' Energy Efficient Loom

This loom works at 50 ppm, compared to 20 ppm for handlooms and 120 ppm for powerlooms [5]. The fabric production rate is 15 meters/day, compared to 6 meters/day for handlooms and 35 meters/day for powerlooms (10 hour shifts and 50 picks per inch) [5]. There is also the option to motorize this loom entirely in which case its performance is comparable to powerlooms.

It is operated by an operator sitting in front of it and moving the reed with their hands. The reed is connected mechanically with the heddles and a mechanism to transfer the shuttle. The operator's (and I say operator because this can be done without having the skillset of a weaver) primary duty is to ensure that there are no errors in the cloth and correct any that are made apart from providing the mechanical force necessary to turn the gears of the machine. The machine can also be motorized in which case some or whole of the effort to move its parts comes from a motor which can optionally be solar powered. An operator is still required to stop the machine in case of any errors (like kinks in the fabric or a broken thread) and fix them when they arise.

In powered mode, an operator can still be used to provide some of the force required therefore reducing the power requirements and cost (significantly for when the power source is solar).

There are similar designs in the market which use mechanical or pneumatic actuation (like a loom manufactured by Inventor Automation based in Coimbatore, Tamil Nadu which uses industrial automation systems and pneumatic actuators to partially automate the loom) but essentially do the same thing with different noise levels and for different prices.

Figure 9: Pneumatically actuated loom [6]

3.5 Team

The team was composed of three members including myself.

GN Raghu: An engineer with experience working in the development sector and with NGOs.
Apoorva Sahay: An anthropologist with experience in the fabrics industries and NGOs in India.

I led this project as the designer carrying out research with their assistance and then designing and prototyping the concepts and the final product.

3.6 Research Process

Though I was given an existing design to work with, I felt that this project required finding a technological solution to a very complex issue with ecosystem, economic and philosophical questions and it would not be very useful if I jumped straight to working on building a technology without studying if it was the right solution to begin with.

This project fell neatly in the category of products embedded within complex systems and I felt that it would be a great way to work towards understanding the intricacies of designing in this environment so I started with a clean slate. Rather than beings solely user-centric (whether it's the user's financial, market or work quality needs), I would study the entire system to learn about the following:

1. The history of the industry – historical background of manual weaving in India, its cultural relevance and significance in the country.
2. The envisioned future state for the industry – what people within and outside the industry think it should be like and why. This includes spheres such as business viability, market efficiency, the well-being and empowerment of the workers, and quality of the output.
3. The policy environment – how government policies impact the production and distribution of the products being manufactured, the machines used for manufacturing, the distribution structures and the market dynamics.
4. The weavers' preferences and needs – what kind of improvements would they like to have in their machines, what kind of work they do, what kind of work would they like to do and what kind of changes would they like to have in their quality of life and livelihood.
5. Grass-root innovations – what kind of improvements were already being implemented by weavers themselves or local businesses as an indicator of unaddressed needs.
6. The market – the operations of cooperatives, businesses, NGO's and government agencies, their preferences and limiting factors.
7. Supply chain – the nature of the weavers' involvement and their share, opportunities available to sell their products and earning arrangements like risk sharing, fixed salaries, wages per unit of product, and opportunities for the marketers.

With this in mind, the stakeholders I identified were:

1. Weavers
2. Weavers' cooperatives
3. Government agencies operating in the market
4. NGO's operating in the market
5. Businesses operating the market
6. Regulators
7. User innovators and grass-root innovators
8. Researchers and academics

Primary research included interviews with weavers, grass-innovators, government agencies, businesses and NGOs. Subjects for the interview were identified by visits and cold calls and through searching for people online and through our network. Subjects of the research also linked us to other subjects after learning about what we were working on.

Secondary research was done by studying published literature, news and opinion pages was conducted to get a better understanding of the broader system and the opinions of people involved in the industry.

3.7 Primary Research

Weavers:

We traveled to the weaving village of Negamam in Tamil Nadu to interview several weavers weaving different kinds of cloth for different purposes and using different kinds of looms to carry out their work.

Some of these are shown below:

Figure 10: A jacquard pit loom

Figure 11: A jacquard frame loom

Figure 12: A frame loom weaving *ikat* designs shown in the picture

The interviews with the weavers revealed their needs as the following:

1. Physical comfort – The loom pedals took a toll on the weavers' knees after extended use. Pit looms were more comfortable than frame looms but both could be better. Jacquard pedals were harder to press than pedals of looms without jacquard. The reed movement also got tiring for the arms after extended use.

2. Productivity – Increased production per day would result in higher income for weavers who were paid according to the amount of fabric woven.

3. Creative control – Weavers were provided yarn and jacquard punch cards or the design of the fabric by the contractors who were either master weavers (weaver entrepreneurs), businesses, NGOs or government agencies and required to supply finished cloth. Some weavers expressed a desire to have a say in designing the fabric.

One weaver went so far as to take learning design and purchasing a computer to help businesses and other weavers design (more on her in the section about grass-root innovations).

4. Price – Most weavers (barring employees of NGOs) owned their own looms and produced cloth that they received orders to produce through the various marketing and distributing channels. The weavers themselves would be the ones purchasing any device that we make and price was a big consideration for them.

5. Loom preference – The looms that weavers used were in many cases decades old and weavers had strict preferences since they were used to working on their own looms.

Government Agency:

The central government agency that works in this space is called KVIC (Khadi and Village Industries Commission). KVIC certifies non-profits to carry out its work and provides them access to its channels for sourcing and distribution. KVIC and KVIC certified organizations work like a walled garden sourcing only from their own sources (raw materials and weaving) and selling and distributing only at their own premises or at other KVIC centers. KVIC products have handspun yarn and are hand-woven. State governments also support handlooms through state apex bodies which source and market products which are handwoven through a network of weavers or cooperatives that work solely with these bodies.

We visited one such center outside of Coimbatore. They had cotton pre-processing, cotton yarn making, silk yarn making and a finished products sales unit. They manufactured steel and wood furniture as well. They also had coconut and banana plantations and a biogas plant. They operate by issuing tenders through newspapers to source cotton and cocoons. Once they have manufactured yarn, they send it out to contracted handloom weavers who are only allowed to weave for them.

Figure 13: Silk yarn production at the KVIC center

They had some handlooms which were not operational. They had one solar loom installed by SELCO Foundation which was the product that I was supposed to work on but it was also not being used. They also had solar charkhas (yarn spinning wheel).

Figure 14: Unused weaving unit at the KVIC center

Weavers offer a variety of available designs and patterns to managers at the center and also make recommendations based on their understanding of the market and from what they see other weavers doing. Sales managers pick from a selection offered by the weavers based on their understanding of customers and what sells but occasionally they send pictures of patterns that they want. Making a custom design is expensive and is not usually done. Employees of the center go visit weavers at their site to deliver yarn and pickup finished products. Weavers do not visit the center. If required, they visit the office of the organization in their region.

The final products are sold only through their own channels. They do not distribute to businesses in the region or elsewhere. Apart from the outlet on site, they sell through other KVIC approved outlets in Tamil Nadu. Their own outlets do not sell only the products they have manufactured. They source other products from North India which they can sell.

Buying from KVIC ensures that you are getting genuine handmade cloth but since their product is not available in the market, it is hard to make the trip to their centers. Their offerings are also limited in terms of designs and quality. The upside for customers is that since these centers do not operate for profit, their products are much more affordable than those in the market. This may also play a disruptive role in the market by providing low-cost alternatives and keeping weavers within the ecosystem since there are not many opportunities outside for the kind of work they may be doing.

<u>Market:</u>

We visited the garments market in Coimbatore which is the closest city to see the nature of goods being sold there.

Figure 15: A market for sarees in Coimbatore, Tamil Nadu

There were a few hundred small shops in a network of alleyways. Most of the shop owners were North Indians who have been there for 2-3 generations. Some of the shop owners themselves are wholesalers and distribute to other shop owners in the market. There were only two stores that everyone mentioned which sold handloom products. One of these stores only sold a few products like cloth and vests, the other one sold sarees but none of them had any sort of certification so we were uncertain that the sarees were genuine handloom products. The shopkeepers there spoke about how people would not pay extra for handloom products so everyone only stocks machine made products. In terms of design, we mostly saw plain sarees, embroidered sarees and simple jacquard work sarees. There weren't any weft design sarees on display.

Figure 16: A saree with a simple jacquard pattern on sale in the market

We found more variety of handloom products in some stores in a different part of the city. There were a lot of ikat cloth, block printed handloom cloth and weft designs (checks and horizontal lines) cloth. The owner said they source directly from weavers and go and select patterns and also order patterns that they want to sell. They did not reveal their sources but said that they have worked with weavers from Negamam before. They also mentioned that they had tried to do business with KVIC before but they did not respond.

The general consensus was that handloom is expensive and only reliably available at high end stores. Local stores do not sell it because they know it won't sell, the ones that do sell it cannot prove that it is authentic and KVIC centers do not deal with local businesses.

NGOs:

Both my teammates came from a background in NGOs involved in handlooms so we were able to get data on the NGOs' perspective.

NGOs typically had two models:

1. Marketing and distribution – This is essentially a social enterprise model where NGOs source from weavers in their target area and market their products to customers with the purchasing power to buy them. An example is Khamir based in Kachchh, India [7].

2. Employment – In this model, NGOs purchase and maintain looms and employ weavers to weave at their centers. These NGOs may sell their products directly or distribute to stores or other NGOs, or both. An example is Dastkar Andhra based in Secunderabad, India [8].

Grass-root Innovators:

This was a very interesting area to research. We looked for ideas or products that had already come to the market but at a small scale which were designed by weavers themselves or by local businesses for the weavers. We found some of these through word of mouth by weavers and others through print media and YouTube.

1. K. Poongodi, Weaver, Negamam, Tamil Nadu

   K. Poongodi and her husband both weave in the weaving village of Negamam in Tamil Nadu. They supply their fabric to a local business. She spoke about how difficult it was to get a new design from paper to cloth. Their ancestors who were also weavers would design their own patterns. A weaver must first sketch the pattern. This then gets translated to a graph sheet to mark out where the weft goes over and where it goes under the warp to form a pixelated version of this pattern.

Figure 17: A graph sheet with the pattern

This sheet is then transcribed into a binary pattern which is then punched onto punched cards.

Figure 18: The machine used for punching cards

This is done for a series of punched cards, each one representing one horizontal line or one run of the shuttle. The series of punched cards is then used and tested before it can be used repeatedly to produce the final product.

This is a very labor and time intensive process which is why custom designs are expensive and time consuming to produce.

To combat this, K. Poongodi learnt how to sketch on a computer and convert designs to the square patterns on a software. She purchased a computer and now works as a designer for other weavers. Her neighbor owns a punching machine and together they are able to provide this service to all the weavers in the area while generating additional revenue for herself.

Figure 19: K. Poongodi demonstrating her work on her computer.

2. Karappa, Weaver and Inventor, Sirumugai, Tamil Nadu

Karappa observed how weavers in his village had trouble weaving because of pain in their feet after a chikungunya outbreak. He designed a loom that only required using one's hands to operate. The reed is connected to a flywheel which is connected to the heddles through a jacquard. He was working on attaching a dynamo on to the flywheel so that weavers could charge their phones.

Figure 20: Karappa's loom in his workshop in Sirumugai

Figure 21: The flywheel and gears on the loom visible next to its inventor

Though the loom solved one problem, it was difficult to use because more force was required to operate it. It was also more difficult to reverse or stop at a desired position since it needed a lever to be used which required moving the hands away from the reed and was tied to a flywheel. It was also noisy and heavy and therefore also expensive to produce. The weaver, though very inventive in this case, was in the pursuit of producing essentially a perpetual motion loom.

3. Kumar Avel, Businessman, Namakkal, Tamil Nadu

Kumar Avel purchased commercially available parts of rapier looms and retrofitted them onto powerlooms. We met him hoping to learn if it was possible to do the same for a handloom.

Figure 22: A retro-fitted rapier loom in operation

Figure 23: Close-up of the rapier attachment

We found that not only was the cost restrictive but also it was critical for the rapier that the parts of the loom are coordinated so that it can go between the raised and lowered warp threads without damaging them. If that were done, it would make the loom faster but the amount of improvement would depend greatly on the weaver's speed which could not be changed very much. For a semi-automated or fully automated loom, the time that could be saved was significant.

4. Unknown business, Negamam, Tamil Nadu

One of the weavers we met in Negamam used a foot operated switch which was connected to an electric motor which used a cam to actuate the jacquard. Each time the switch was pressed, the motor turned and the cam pressed on a lever which would otherwise be pressed by foot to actuate the jacquard. There was another motor for the pedal used to turn the jacquard in the reverse direction.

Figure 24: Foot operated switch for jacquard actuation

This was a novel idea since it was flexible and was operated only when the weaver wanted it to be. It was not connected to any other parts of the loom allowing the weaver complete flexibility to weave any kind of patterns. It removed a large part of the effort required to operate the loom.

Some drawbacks were that it required an electric supply, it was noisy, it was not very energy efficient as the motors started and stopped each time the switch was operated and it was low fidelity since each time the switch was pressed, one entire turn occurred. The weaver couldn't choose where to stop or pause unlike when the pedal is operated manually.

3.8 Secondary Research

The first part of research was on the different topologies of the weaving industry. The following were identified:

1. Individual Weavers
2. NGO-owned producing units
3. Profitable/Social Enterprise owned weaving units
4. Disabled weaving artisans
5. Weaving Cooperatives
6. NGO-facilitated weavers' collective
7. Self Help Groups (SHG)
8. State owned apex institutions
9. Cooperatives under apex

These types of organizations interact with each other. Weaving cooperatives and collectives work with the government bodies or are facilitated by NGOs. Government bodies supply yarn at subsidized prices to weavers or cooperatives in their supply chain and then sell the product at their own centers or certified centers.

As is visible, the distribution networks are complex with many competing stakeholders.

There were several opportunities for streamlining the sales and distribution networks so that weavers have more flexibility, higher pay, greater ownership and greater control. It also became clear that what is perceived as an artisanal market is in fact semi-industrial as also noted by historians [9].

There are also strict proponents of the traditional weaving methods for creating a more equitable and sustainable society and for personal development of weavers who are against semi-industrialization of this sector [10]. Gandhi was a firm believer in the village economy and in self-reliance. He was a champion of handspun yarn and handwoven cloth. His influence and beliefs regarding this are alive in many quarters, especially in this sector.

Products like the Sun Kharga (the semi-automated loom) and electric spinning wheels sit awkwardly in a gap where they quasi-industrialize artisanal work which then has to directly compete with industrial looms and mills because the artisan is converted into a laborer by transferring all the skills to the machine and using 'hand power' as an excuse for maintaining their distinction as artisans and of their products as hand-made but that isn't really the case.

The other argument here is of the artisanal weaver and their mental state and personal development as they practice their art/craft. This is not valued or needed in the current economy where only the final product is of value. There is no consideration for the embodied information in the products, only the information directly contained in the product (What did the maker feel and think when they made the product vs what does the user feel and think when they use the product). This results in industrialization winning every time at the expense of de-skilling and dehumanization of the person creating the product. What is the role of the designer in this setting?

Rahul Jain, a historian, talks about how older artisans who are masters of their craft have the centering and demeanor of Sufi masters and younger weavers should aspire for it as well [11]. The problem with this argument though is whether such a thing is actually true on the ground and whether it can compete with livelihood generation and sustenance. Weavers migrate to other daily wage jobs if they pay better. The question boils down to why should handlooms even exist?

There's also the discussion about the nature of work and skill. These products are valued because they are high quality and are sold at high-end stores for a high price. Handlooms are capable of producing very detailed and intricate work which is very difficult to do on traditional powerlooms. They are also valued by the socially conscious for their non-industrial nature.

3.9 Design Direction

Two directions that seemed to emerge were:

1. The well-being and reduction in drudgery of weavers, access to markets and equitable treatment while they produce traditional products in traditional ways.
2. Advances in using technology to design better products and adapt better to the market to be on par with traditional fashion, increase the skills of the weaver and be up to date with the times.

Coming in from the side of developing a technology, we felt it was best to take the first route and work with existing techniques and systems to develop a technological intervention to solve the problems of weavers while also being in line with the ecosystem and promoting values we recognized as strong and inherent to it, namely, preservation of skills and reduction of physical drudgery. We did however also keep in mind the larger picture and think about how the product we design might fit into it as we designed it.

In the long term, weavers should get more skilled in design work. Currently there are too many obstacles to this. In many cases, they do not have direct access to market information, do not source their own yarn or sell to the market directly. Furthermore, there are a lot of steps involved between a design on paper to a design on cloth which require other people and skills which the weavers themselves do not possess.

We felt that there is an opportunity in creating solutions which raise the skill level of weavers and empower them. High quality and high design cloth is where higher wages are and it is these industries which are at a comparatively lower risk of encroachment from power looms. While it is the need of the hour to improve the conditions of existing weavers, the next steps should be taken in this direction.

3.10 Design

I started by thinking about how to best reduce the physical effort required without automating the loom. I decided to work on each individual part of the loom separately so that the weaver has flexibility while weaving. I did not want to design a loom also because weavers have their own preferences in the loom and it would be much more useful to design a product that could be retrofitted to any loom. What I wanted to design was essentially a power-steering type of system for the loom.

Technical challenges:

1. The device had to be low-energy and low cost to pair with a solar power system and still be affordable.
2. It needed to be able to fit on any loom and any part of the loom.

3. While the treadles and jacquard are actuated using a pedal (the heddles) therefore allowing sensing of the force between the heddles and them, the reed was moved by pushing and pulling the reed itself making it a challenge to sense force and apply it at the same time.
4. The device needed to be very easy and intuitive to use.

The third point above was the most challenging. I needed to sense a force on a body and then apply a force in the same direction without any lag.

I achieved this using a servo motor at the pivot around which the reed moves. The servo motor provided a reaction force which was then sensed on the motor using a force sensor. These were paired to a micro-controller which sensed a force and applied a proportional force in the direction of the force. There was no perceptible lag. The amount of force coming from the motor and its direction could be adjusted using a dial and a switch. We were able to design a device with very few parts that could be attached to any part of the loom. This kept the energy requirements and cost low and felt like a power steering does while being used.

We built a scale model of a loom with a frame and the reed with some fabric tension on the reed to prototype and demonstrate the working of this device.

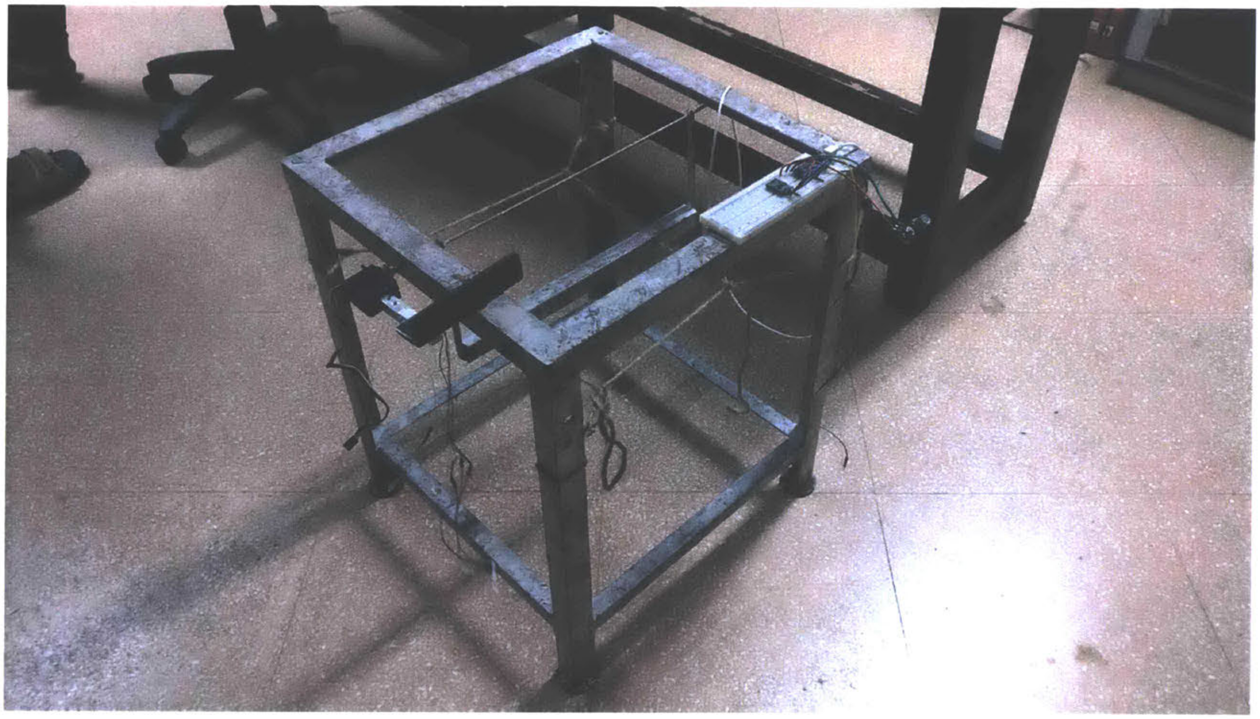

Figure 25: Scale model of a loom with the device attached

Following are some images of the prototyping process:

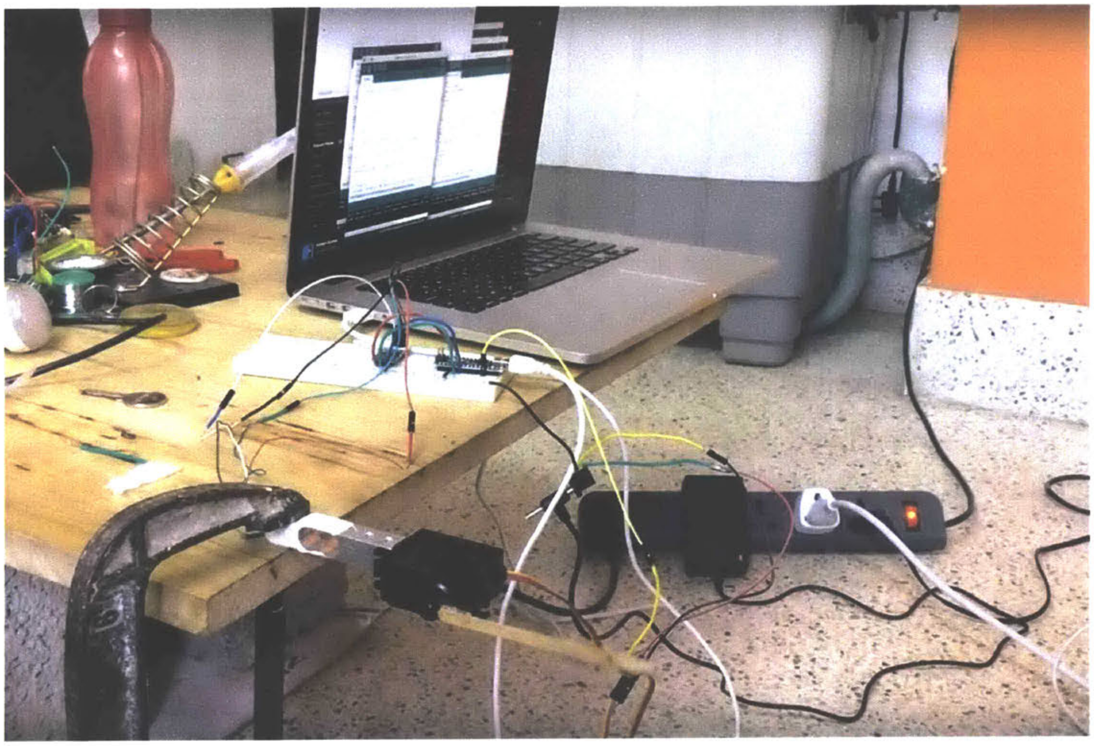

Figure 26: Servo motor and force sensor

Figure 27: Building the scale model of the loom

Strengths of the design:

1. Easy and intuitive to use with precise control while reducing the force required to use the loom by any amount the weaver desires.
2. Retains full functionality of the loom and the independence of the different moving parts therefore retaining the skill required to weave and the capability to weave intricate and high quality cloth.
3. Retains the 'feel' of using the loom.
4. Can be attached to any loom and any part of any loom.
5. Low cost and low energy consumption.
6. Does not have spikes in power consumption due to the use of a servo motor.
7. Retains the handmade nature of handloom cloth.

One drawback is that it would theoretically be possible to use the force reducing devices on each part of the loom and then automate it completely using a microcontroller. To combat this, the force reducing devices only respond to applied force but are capable of providing another microcontroller with information of when and how much force is being applied.

A pilot site has been identified in Tamil Nadu and a final product is currently being developed.

3.11 Future Steps

To address the remaining needs and ideas around handloom production, I envisioned a system where the availability of solar power can open the door to the use of an electronic jacquard system so that weavers would no longer need to rely on punched cards and the lengthy process of getting designs from conception to the final product. This system could be paired with a smartphone which could enable the weaver to design patterns or use existing patterns and transfer them directly to the electronic jacquard. Current systems are reliant on desktop computers to design and transfer the designs. This would give the weaver more control over their designs and more choice while drastically reducing the cost of bringing new designs to the fabric.

The smartphone app could also operate as a marketplace so that designers or customers themselves could order designs of their choice online. They would know exactly who weaved it for them and know for certain that it was handwoven. The orders could also pass through organizations, business or NGOs.

The force reducing device could act like a sensor of movement of the loom and this information could be used by the app to control the jacquard.

This system is illustrated below:

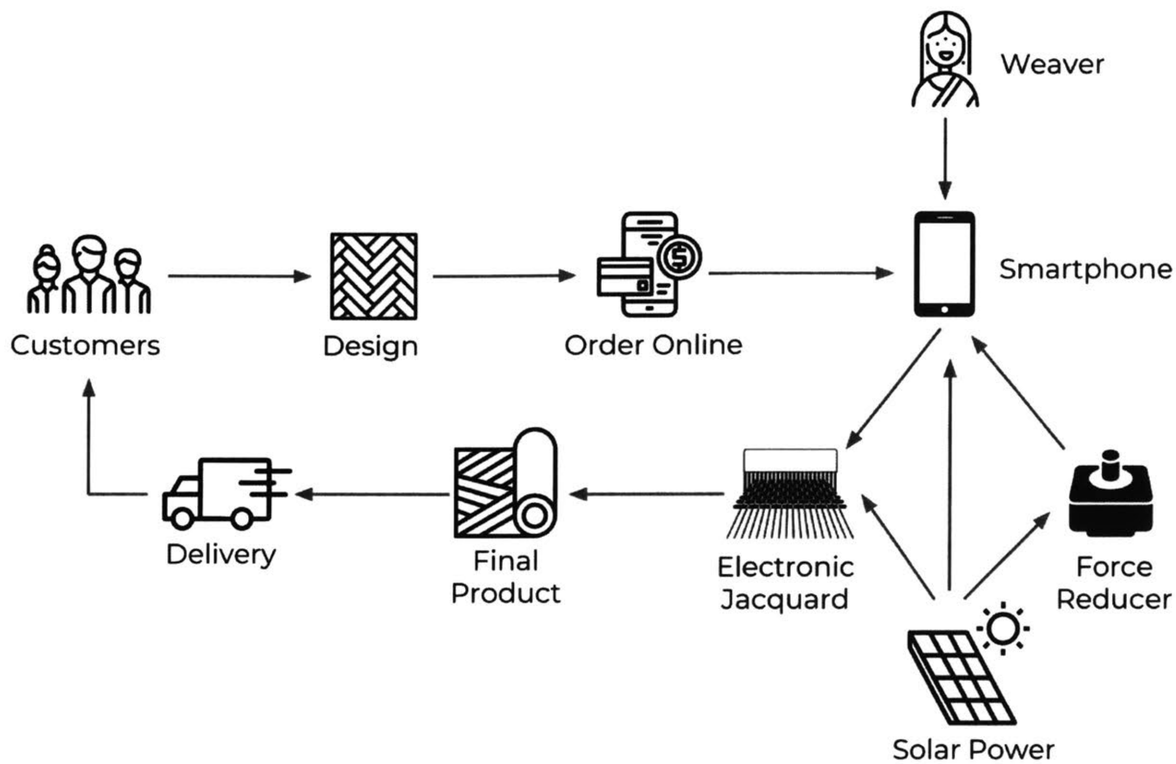

Figure 28: Envisioned future system of handloom production [12]

3.12 Design Framework Learnings

1. Researching the structure of the system around the product is absolutely crucial to its development. Design cannot be done in isolation with narrow considerations.

2. Studying multiple stakeholders and not just the user provides great insight on the forces acting for and against any concepts. It helps recognize needs across stakeholders and provides an opportunity to find synergies and solve more problems for multiple stakeholders and reduce resistance against the product.

3. The research must be approached first for its own sake and not with a solution in mind. Even the limitations of the type of solutions that one has the capacity to develop can be

a hindrance and create bias.

4. Research into systems leads to discovering more and more dependencies. The designer must recognize the important ones and focus on those. The foggy early stages of the research can lead to confusing and jumbled mess of information that can be hard to analyze.

5. Thinking simultaneously about the large scale and the small details is very important. Keeping the entire system in mind while designing and making sure that the details are right leads to better outcomes.

6. Constraints are not the most important derivations from contextual elements though they are usually the first ones to be recognized. Contextual elements help provide a design direction and design goals when probed deeper.

7. Having a design philosophy serves as a great guiding principle. It serves to manage ambiguities and stay grounded and directed.

8. It is useful to recognize trends within the system and the forces behind them. These can be utilized to serve the product or acted against when they are detrimental to the system. Understanding the structure and dynamics of the system helps recognize high leverage areas that individual stakeholders may not have recognized.

9. System cues are very useful in reframing the problem.

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Chapter 4

Case Study 2 – Biogas Generation System Based on Food Waste

(Product as a component of a system)

This case study describes the design process of a biogas plant which uses food waste from the city's waste stream to generate energy in individual households which have installed the plant. This required designing both the plant itself and waste collection and distribution system. Since the plant relied on the system, design goals were derived from it. Subsequently, the ability to fulfil these goals allowed for the creation of the system.

This makes it a good example of a product-system arrangement where the product is a component of a system and both need to be designed to work together successfully.

4.1 Introduction

Biogas is a gas consisting mainly of methane and carbon dioxide. It is generated during anaerobic decomposition of decomposable matter like dung and organic waste. This project explores how this technology was used in the form of a product that individual homeowners use. This product then opens up opportunities for a system of waste collection and distribution to be created. It falls neatly in the 'products as components of a system' category since a lot of the design goals arose from the need to build the system and would not have been discovered if the system was not designed along with the product. Together they create a more robust and useful solution to the problems of sustainable energy generation and urban waste management.

4.2 Background

This project began in 2012 and stemmed from my bachelor's thesis which studied the technical performance metrics of biogas generation systems based on food waste. I found that these systems were over two magnitudes more effective as compared to traditional biogas generation systems which relied on cow dung in terms of mass of feed and volume of the digester required for similar amounts of energy generation. This was because of the higher energy density of food waste and a different digestion process. This presented a great opportunity to study how this technology could be adapted and productized for widespread use. While some products did exist on the market, they were very similar to plants based on cow-dung and had the problems with reliability and productivity.

To design and develop this product with the right understanding of customer needs and the ecosystem but without much funding to carry that out, I started a business of constructing small units (0.5 – 2 m^3) in households and institutions in and around the town of Manipal, India. This gave me the opportunity to understand the existing product deeply and interact with several customers and potential customers of the product.

4.3 Existing Design

Anaerobic digestion has existed as a technology for processing waste and/or generating energy since the mid 1800's when it was used for sewage treatment [1]. The 1970's saw a widespread dissemination of biogas plants in developing countries in rural areas to use cow dung to generate energy [1]. Biogas was largely seen as a byproduct of anaerobic digestion which was used for waste management but not used primarily for energy generation until this period.

Biogas plants which work on food waste for household use rely on similar technology and form at a smaller scale so that households can install them and use the organic waste as a fuel source to gain some savings on energy costs and dispose their waste cleanly. There are several manufacturers on the market and government subsidies are also available to customers and manufacturers. Large-scale biogas plants use different processes for processing of the feed and generation of the gas.

I constructed plants based on the ARTI design which uses commercially available components to create a biogas plant. The many manufacturers on the market use their own designs and manufacture their products from scratch but followed the same underlying structure. The ARTI design is shown below:

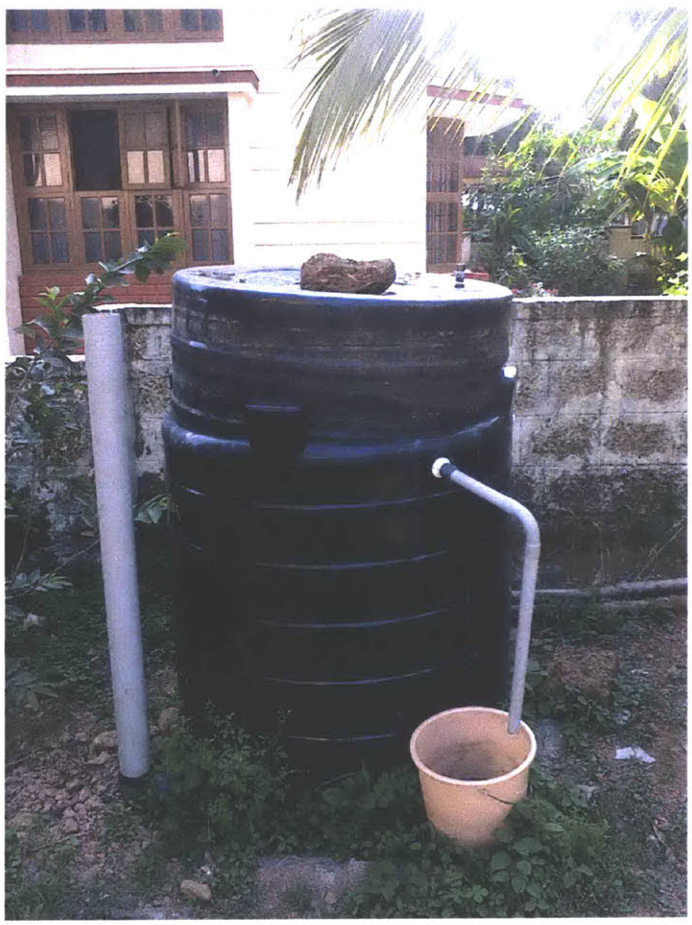

Figure 1: Food waste based biogas plant for household use

The lower tank is the digester. This is where the food waste is converted into gas. The upper tank is where the gas is stored. It rises as more and more gas is generated. The pipe on the left is the feed pipe used for feeding the waste. The pipe on the right is the overflow pipe through which spent liquid is removed. This can be used as garden fertilizer.

4.4 Opportunity Identification

To look for opportunities in the area of sustainable development for semi-urban and rural areas, I spent a few weeks visiting different businesses like farms, rice mills, forges, machine shops, restaurants and retailers, institutions like schools, colleges and temples, and households of different sizes and socioeconomic conditions.

Schools were required to provide lunch to students. They used LPG (liquefied petroleum gas) cylinders to cook these meals. I discovered that because of the unreliability of the supply of LPG and issues related subsidies and reimbursements, the delivery of LPG cylinders was often delayed and on these days, no food was cooked and the children went hungry. While LPG was subsidized for household consumption by the government and schools also received subsidized LPG, commercially available un-subsidized LPG cost over twice as much. This made it difficult for schools to purchase it commercially in case their usual supply was delayed.

I felt that there was an opportunity to use biogas in schools to generate cooking gas from the leftovers of the lunch that was provided to students.

4.5 Biogas in Schools

I installed the first biogas plant in a school near Manipal in late 2012. The school was a small school with sixty students. They had a kitchen with a single burner stove run on LPG. The plant was installed in the compound of the building housing the kitchen. The students helped build and subsequently run the plant.

The following are some images of the installation and running of this biogas plant:

Figure 2: Assembling the biogas plant

Figure 3: The completed biogas plant

The students fed the leftovers from their plates after they were finished eating into the feed pipe of the biogas plant. The staff fed leftovers and kitchen waste into the plant. It produced about 50% of the energy requirements of the kitchen. More importantly, the additional stove made cooking quicker and days that LPG was delayed, food was still cooked.

I discovered a lot of issues with the product as I helped run this plant along with the school staff and students. These were as follows:

1. The plant was extremely sensitive to over-feeding. This could occur if too much waste was fed or if the waste was in large chunks which took longer to digest which over time

piled up inside the plant.

2. The plant was difficult to maintain because once over-feeding occurred, the process would start shutting down and the gas would start smelling strongly. It was difficult to revive the plant once it was in this process since this was a result of a reinforcing loop in the microbiological processes. If the process stalled entirely, the plant would need to be emptied and restarted which would take weeks to do.

3. The food waste available was not sufficient to fulfil the entire energy requirement of the establishment.

4. The return on investment consequently was poor with a long breakeven period. This was made longer because of LPG subsidies.

5. The product structure also required improvements. Waste would sometimes get stuck in the feed pipe causing blockages. The exposed stagnant liquid in the digester was an ideal place for mosquitoes to breed.

6. The product seemed to at best, rationalize generation of waste and at worst, incentivize it.

Though some of these issues could be resolved with better training like being careful and timely with feeding the plant, and with minor improvements to the plant design like a valve to release blockages and using a layer of oil on top of the exposed liquid to prevent mosquitoes from breeding, it was clear that a product redesign would make it much easier to sell.

Problems with reliability and energy content were harder to solve. These were dependent on the underlying microbiological process itself. The lack of sufficient waste was mitigated somewhat because the cook also fed food waste from her own home which was next door to the school. Waste was sometimes also brought from the teachers' homes or from a nearby eatery. This was an interesting development to have happened.

I subsequently installed several more plants in schools since it was also a great way of teaching students the ideas related to sustainability, waste and energy.

Figure 4: Constructing a biogas plant in another school

Figure 5: The finished plant

Figure 6: A plant in a third school

Figure 7: Piping for the gas

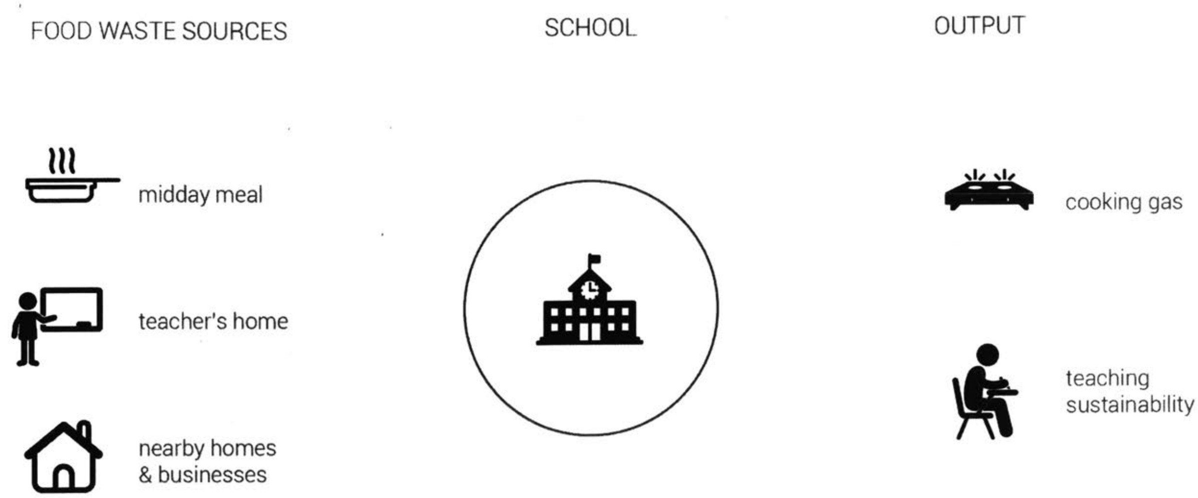

Figure 8: The model for biogas plants in schools

This effort was very useful for conducting thorough research by working on the plants and interacting regularly with the people running the plants. It helped to identify the requirements of the users and also possibly mating with external waste streams since it had occurred organically in this project which validated the idea and its acceptability within certain conditions.

4.6 Biogas in Homes and Institutions

I then focused my energy on trying to expand to other types of customers like households and small institutions. I also experimented with different sizes and different architectures for the product. This provided insight on the form of the product that was most preferable and information about the requirements of a different set of potential customers.

The following are some of the units that were constructed:

Figure 9: A 2 m^3 plant at a household based business

Figure 10: A blue flame with a stove similar to an LPG stove at the household based business

Figure 11: An 2 m^3 underground plant at an orphanage with feeding chamber and shed

Figure 12: A 0.5 m^3 plant at a small household

The problems of reliability and maintenance were persistent despite spending larger amounts of time on training. Plants smaller than 1 m^3 did not provide great utility but were expensive and harder to run therefore a constraint was recognized. It also became clear that the best possible condition for the product was for it to be as unobtrusive as possible since the ideal case for customers was having a product that they could install and then forget.

Following this, market research and user interviews were conducted to study the preferences and requirements of homeowners and institutions of different socioeconomic conditions and sizes, and their motivations for investing in a product of this nature. I also interviewed customers of other manufacturers to learn about their experience.

I studied a model based on a large scale plant (> 5 m^3 capacity) and distribution of the gas. A community owned model had been championed by the Indian government for cow-dung based plants but had not been successful. Large plants require much more attention and often rely on different processes to run. They require a larger space to be set up and someone skilled to run the plant. Small institutions do not have the capability to run such plants themselves. I realized that the technology and the model required to run such an operation was not optimal for this application and market conditions and decided to focus on pursuing improvements in small-scale plants.

It started becoming clear that if there were a way to utilize the segregated organic waste stream of the town which consisted waste from large sources like restaurants, the hospital and the temple and use that to generate biogas in the homes of people, the utility of the product would increase manifold.

To develop this idea further, I did a survey of some of the largest food waste sources like restaurants, dining halls and cafeterias in the town of Manipal. I estimated the quantities and mapped the different waste management channels and their economics. I discovered that the municipality did not collect food waste and it was managed by small businesses. I used this data to simulate a system where food waste could be collected from waste sources like it was at present, processed and then distributed to individual households who had biogas plants installed. This system had many benefits, namely:

1. Biogas plant owners would be able to satisfy all their energy needs for it or whatever amount they could afford. They would not be limited by the waste they produced themselves while also being able to manage this waste on-site.

2. Since the waste being fed into the plant would be controlled by the distributing agency, the operation of the plant would be smoother and handled by skilled workers greatly reducing instances of failure.

3. The town would benefit from its waste being managed effectively and not ending up on the streets.

4. Fossil fuel dependence would reduce as would reliance on government subsidies on fossil fuels.

This system is illustrated below:

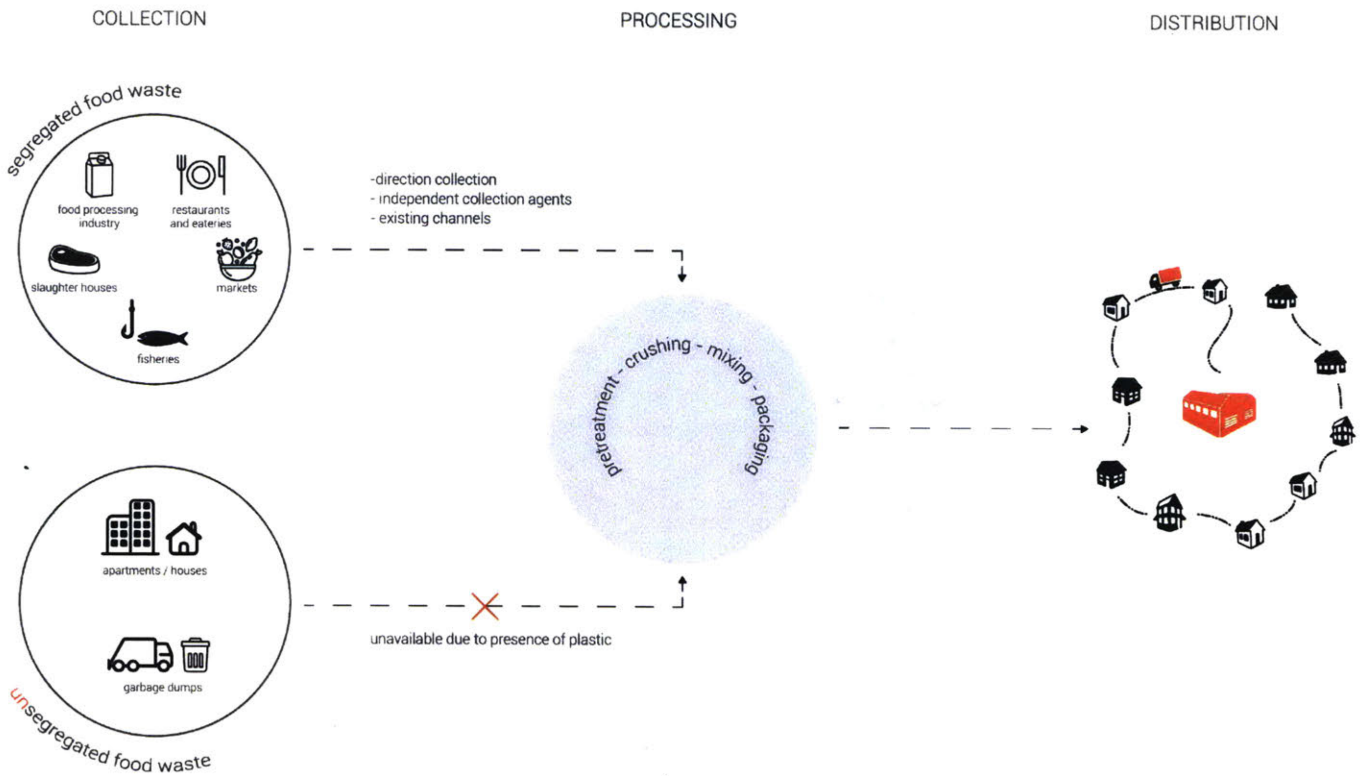

Figure 13: Waste collection and distribution model

Analysis revealed that this model was not sustainable with existing plants since daily collection and distribution and the infrastructure required to support that would not be economical while trying to compete with the long term cost of using LPG instead. However, if waste was distributed to each household once every 4 days, this model broke even for the town of Manipal. If the plants could be fed every x number of days, the same distribution infrastructure could serve x times the number of households which reduced capital costs as well.

Figure 14: Waste distribution over a period of seven days

It presented a new design goal of designing a plant that could be fed intermittently (aiming at once every 7 days) but that could generate gas consistently. This was challenging because the plants were very sensitive to overfeeding and would fail at overfeeding as low as 20%. Pushing this to 600% would be a large challenge.

4.7 Design

I redesigned the plant from scratch using processes that are used in large-scale plants to be able to handle large amounts of feeding without greatly multiplying the volume of the digester. The plant had the following features:

1. Self-sufficient, not requiring external energy like large-scale plants for pumping the digester fluid.

2. Reliable gas generation due to process automation.

3. Filtration of waste allowing for unsegregated waste to be introduced into the plant.

4. High volumetric efficiency requiring lesser volume than existing plants for processing the same amount of waste.

5. Eliminating the need to pre-process or crush waste.

Most importantly, it allowed for the creation of a profitable system of waste collection and distribution. The logistical network that this could create opened up other possibilities such as markets for organic fertilizer from the fluid overflowing from the biogas plants and sale of excess unused biogas.

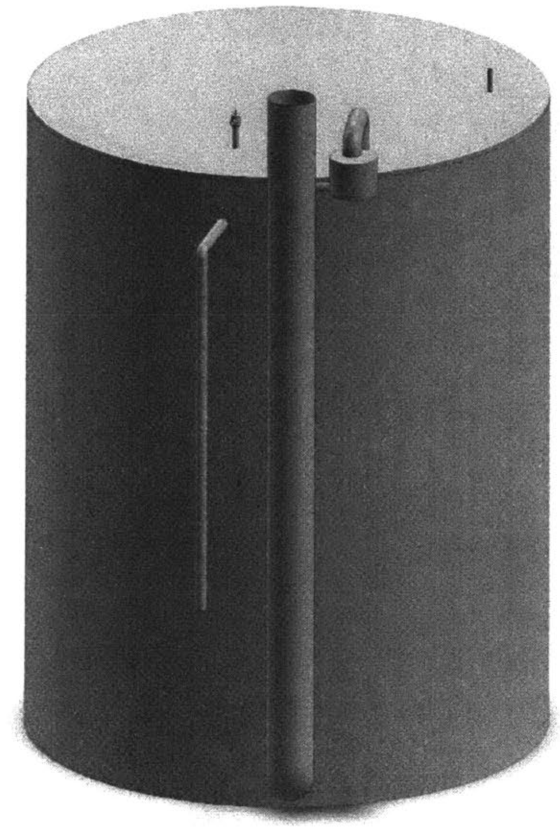

Figure 15: Model of the digester

I named this system 'Nivu'. It is illustrated below:

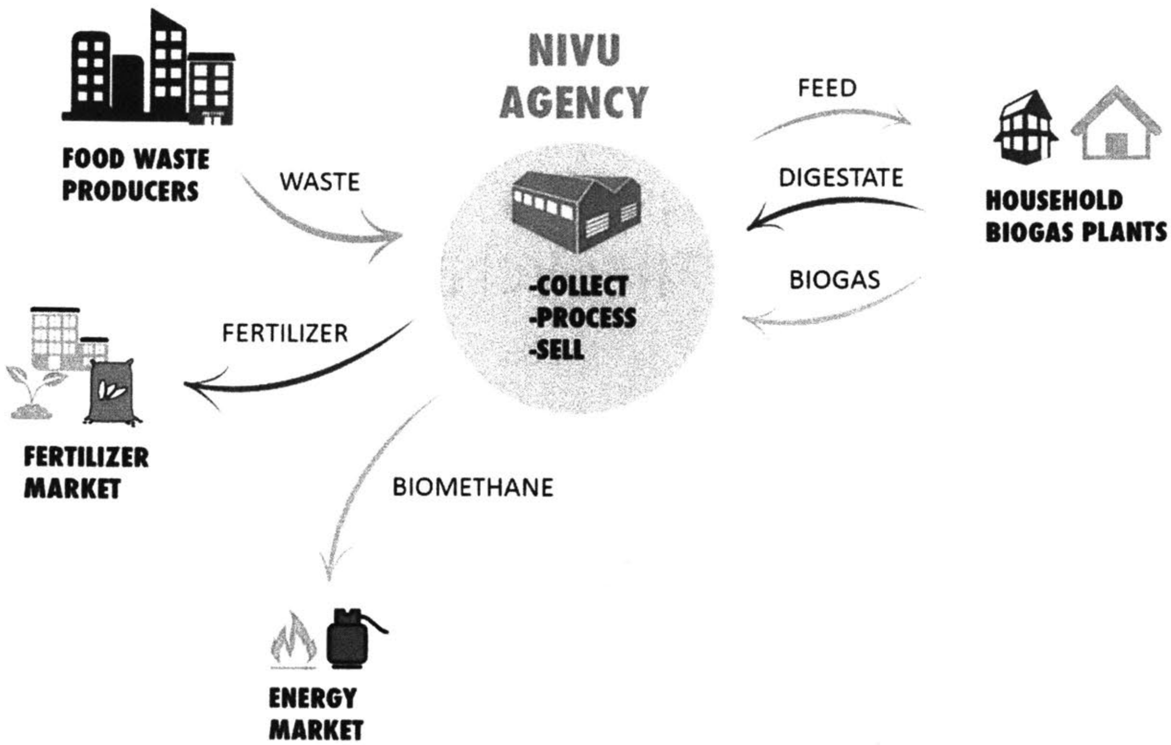

Figure 16: Possible future system based on the biogas plant

4.8 Design Framework Learnings

1. Recognizing that a system may be a necessary part of the design is not intuitive. Research and validation must be the basis for system design. A system must not be conceptualized to fill gaps in the design without verifying that the product cannot itself satisfy these requirements. The product should be the least complex possible.

2. Individual parts of the system must be strong themselves and fulfil requirements of the stakeholders involved. Other parts of the system must not be relied on heavily to fulfil these requirements. This creates complexity and increases chances of failure.

3. The envisioned system can be thought of as a stakeholder and its requirements must be rigorously fulfilled by the product for smooth operation.

4. There should be sufficient margins and buffers because the roll-out of the system will reveal more information which must then be used to refine the design goals of the product and the system.

5. When the product is a component of a system, it can often seem like a chicken or egg problem. Having a roll-out plan helps prioritize design decisions.

6. Any changes made to one component of the system propagate to other components. The system must be reanalyzed to make sure all the components are streamlined.

7. Complex problems take time to reveal themselves at a degree where a useful intervention can be made. It is important to be observant of all details and spend enough time with the problem to be sure that the solution being proposed is not superficial and uninformed.

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Chapter 5

Case Study 3 – Virtual Assistant and Online Platform for People with Vision Impairment in India

(Product as a system)

This case study describes the design process of a platform for information, products and service delivery with a virtual assistant built on top of it designer for people with vision impairment in India. The users interact with virtual assistant which is an interface to the platform and further information available online. The platform is used by various product and service providers, people with vision impairment, and people and institutions associated with people with vision impairment.

This makes it a good example of a product-system arrangement where the product is itself a system.

5.1 Background

This project started in late 2012 with some curiosity about people with vision impairment in India. I started by visiting an NGO, the National Association for the Blind in Bangalore for one afternoon and interacting with people with vision impairment and the people running this NGO. Since then it has taken a winding route to become what it is right now.

In the course of this, the project has been supported by the National Association for the Blind, MIT IDM, MIT Sandbox and the Legatum Center in different phases of its development.

5.2 Demographic Information

The estimated number of people with visual impairment in India is between 8.8 million [1] and 12 million [2]. Another 47.7 million people have moderate to severely impaired vision [1].

5.3 Research

The following pages describe the design process chronologically as it occurred, not in separate phases of the design process. This is to illustrate how the ideas grew in scope and scale and how the iterative process of designing and getting feedback from various stake holders acts as research.

Following the initial trip to Bangalore, the project started in earnest in 2014 with some interviews with people with vision impairment at the National Association for the Blind (NAB) at their branch in Mumbai along with interviews of the people managing the NGO and trainers at the mobility training centers.

I learnt about their lives and their problems with everyday tasks. I discussed these problems with the trainers and heard their opinions about what could help. I also had discussions with the heads of the NGO to talk about how they tackled these challenges at the institutional level.

Figure 1: A person with vision impairment learning how to use the cane at NAB, Bangalore

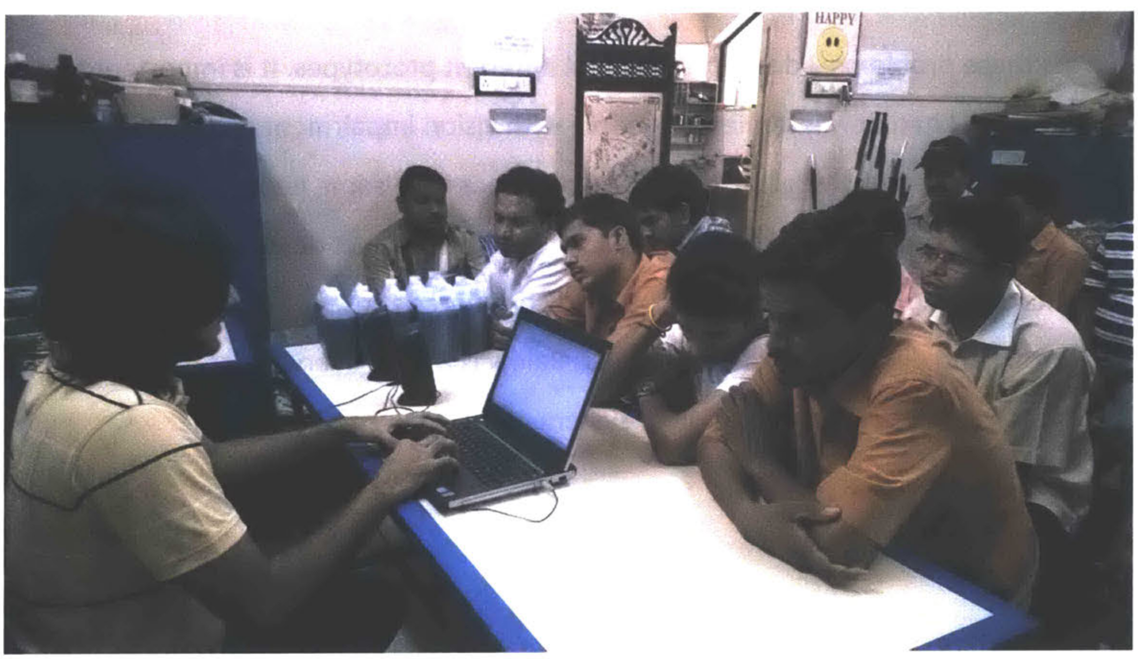


Figure 2: Meeting people with vision impairment at NAB, Mumbai

During these first round of interviews, I learnt about challenges with being independent and mobile faced by people with vision impairment. My big question at this point was why despite all the technological development enjoyed by able-bodied people, the best tool still available to people with vision impairment was a folding white cane. I also felt that what I could offer was a physical product based solution. My questions and subsequent observations therefore were focused on this problem. These are as follows:

1. Problems sensing head and chest level obstacles.
2. Some trouble with walking in a straight line without any guiding infrastructure.
3. Detecting drop-offs is difficult until the last minute.
4. Accidentally hitting stray dogs with the cane while walking on the street
5. Moving in crowded places like railway stations is difficult because people do not always notice them.
6. Sensing puddles during the rain is difficult often resulting in wet feet.
7. Moving indoors was often problematic as well but it was not always the right environment to use a cane.

To address these problems, I developed several different prototypes. It is important to note that at this stage I had only interviewed people with vision impairment and some mobility training instructors extensively. I had had conversations with some people in the management of NGOs but had not actively incorporated those into the product development process in terms of the design of the product itself but had considered those ideas as useful in the manufacturing and distribution of the product. Below is a brief overview of the first rounds of design before I move to the integration of system aspects.

5.4 Initial Design

The first prototype that I developed was an obstacle detection system mounted on the cane. I used commercially available ultrasonic sensors which are used in cars. These are dust proof and water proof and give a reasonably accurate reading at close range (up to 1.5 m). The feedback was provided haptically using a pair of vibration motors.

Further research into this idea revealed deeper insights. Users wanted a product that would give them relevant information in an unobtrusive way. Output from the device was not useful if the object being sensed was unlikely to be an obstacle or was too far away. The feedback from the device was also preferred to be intuitive and quick to gauge.

The prototype is shown below:

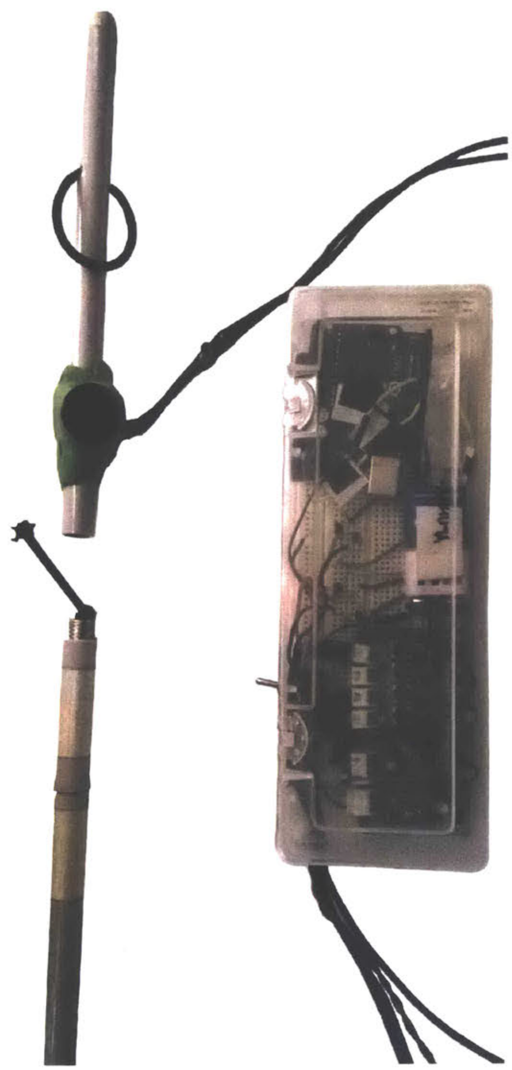


Figure 3: Prototype of obstacle detection system

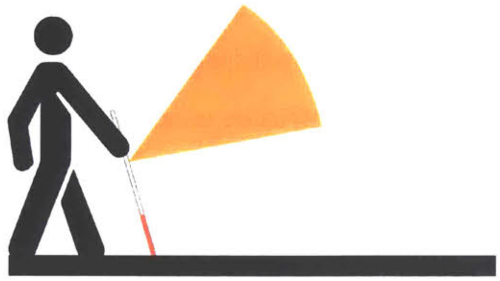


Figure 4: Range of ultrasonic sensor

Figure 5: Testing the obstacle detection prototype

This prototype had all the necessary features and would cost less than a third of a competing product in the Indian market and over sixty times less than any device available internationally.

Further development was done on other concepts that addressed user needs for the purpose of testing and eventually arriving at a final design.

The next concept aimed to address the problems with orientation and walking straight. I used a magnetometer and accelerometer mounted on to a white cane along with an Arduino Nano. The software was essentially a 3D compass. The user could point in a direction with the cane to register their intended direction. After that, every time the cane crossed that direction as they moved it from left to right and back in front of them while walking, it would vibrate gently.

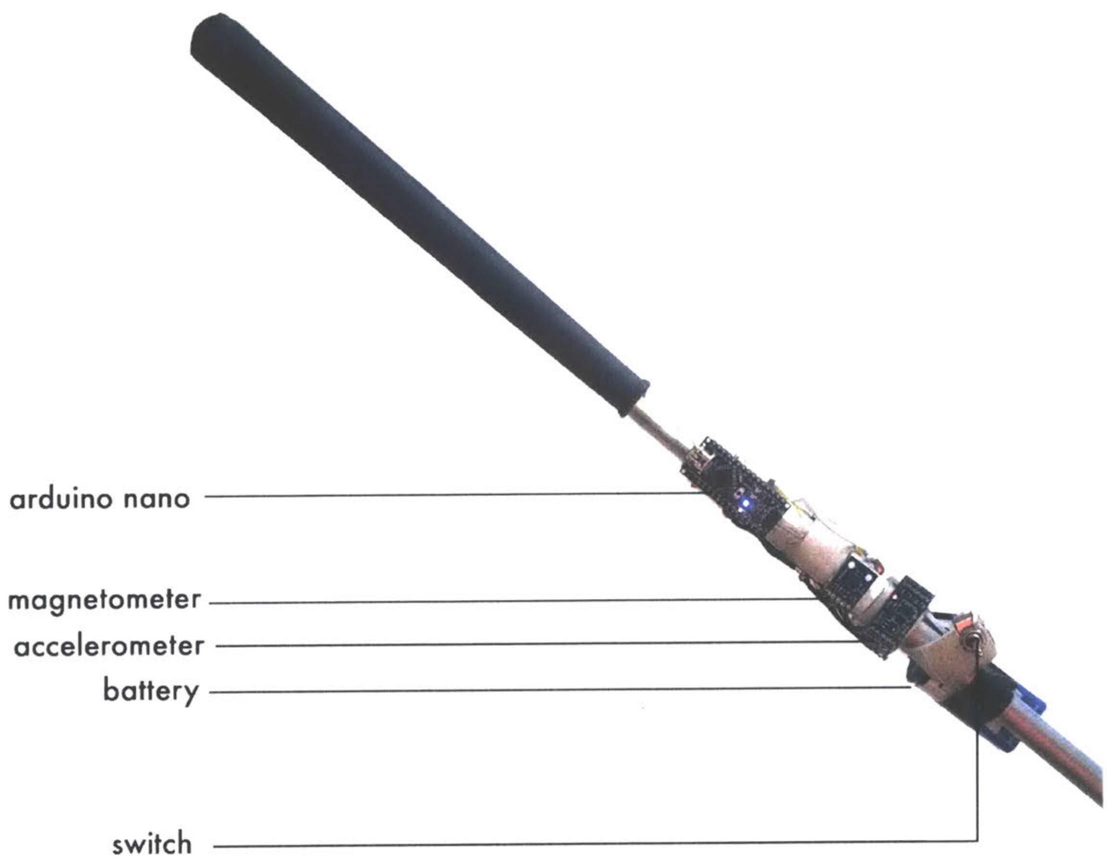


Figure 6: Orientation guidance system

The device received positive feedback from some users who we tested with. There were some technical challenges still to overcome, namely the well-known lack of precision of low-cost accelerometers and magnetometers.

At this point I felt that the folding white cane which was manufactured by different NGOs, each using different designs itself had many flaws. These were as follows:

1. The joints were not very strong and the canes were prone to breaking.
2. The canes were heavy.
3. The elastic used to hold all the pieces together was difficult to change if it broke.
4. It was not possible to get different grips on the cane.

To address these, I worked with the NAB manufacturing unit that produced white canes to develop a new design for the cane. Also of note was the fact that the manufacturing unit was staffed almost entirely by people with vision impairment (a feature not unique to NAB). Apart from designing a good and useful white cane, I also had to make sure it would be possible to manufacture in this setting.

The cane I designed is shown below:

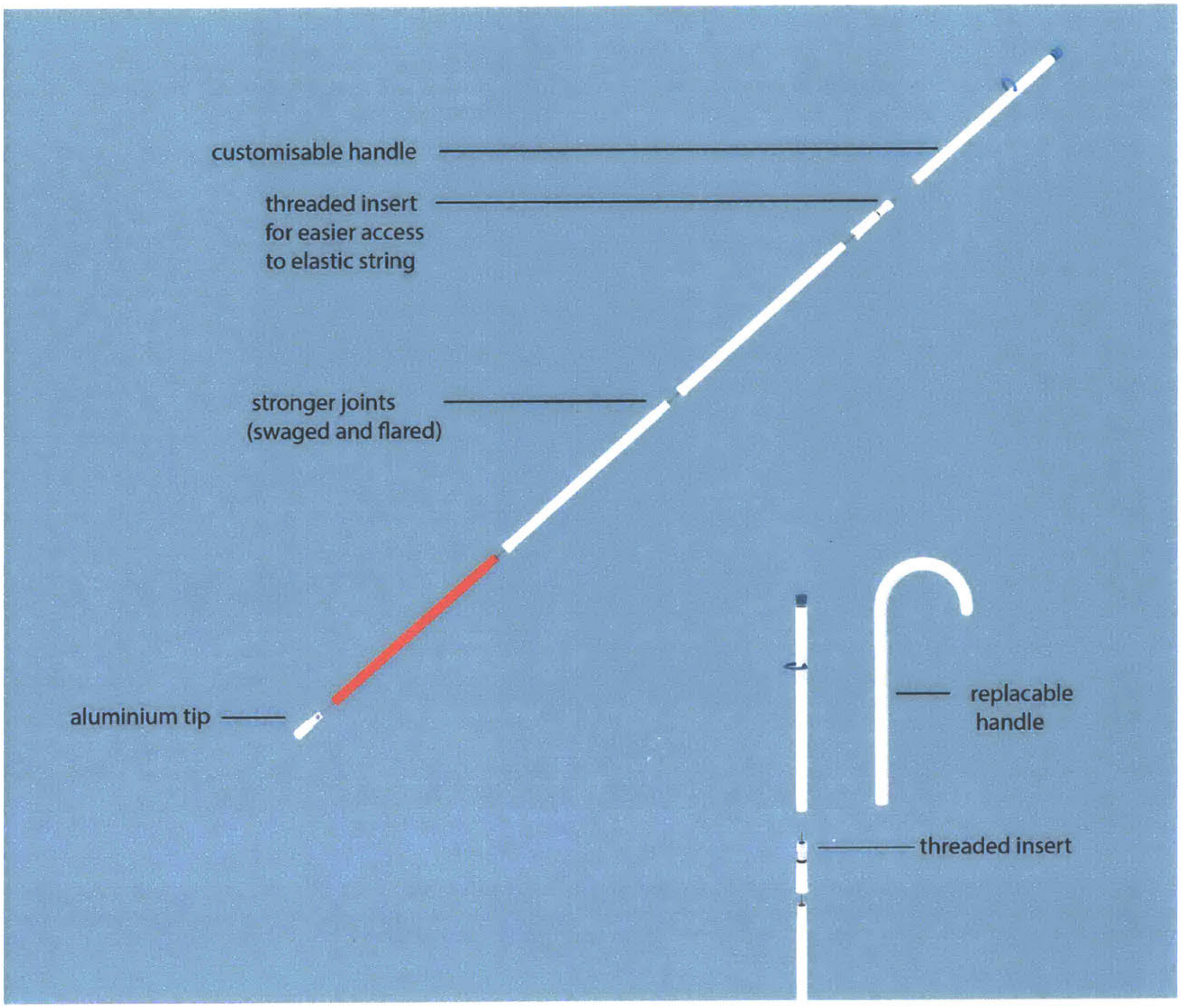


Figure 7: Design of the folding white cane

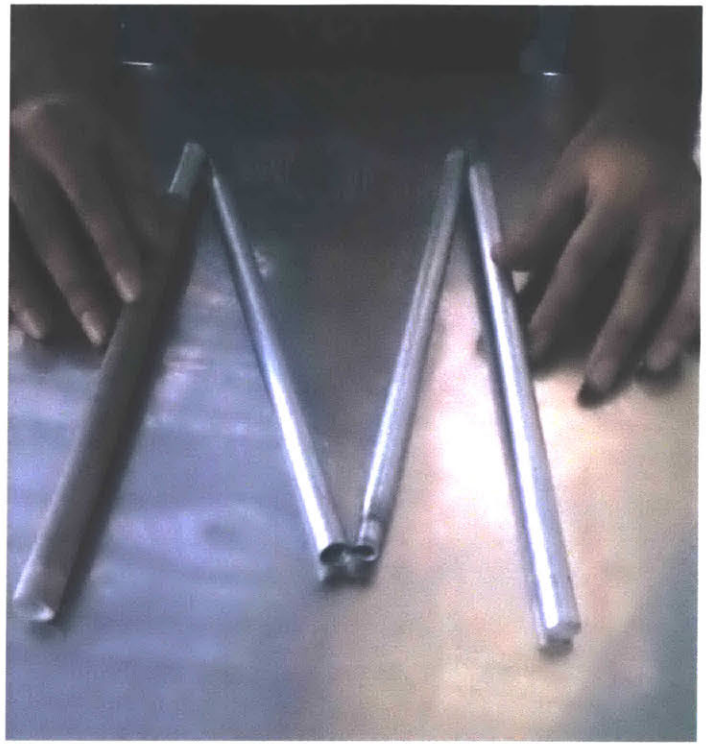


Figure 8: The first prototype of the cane

Figure 9: Manufacturing the first batch

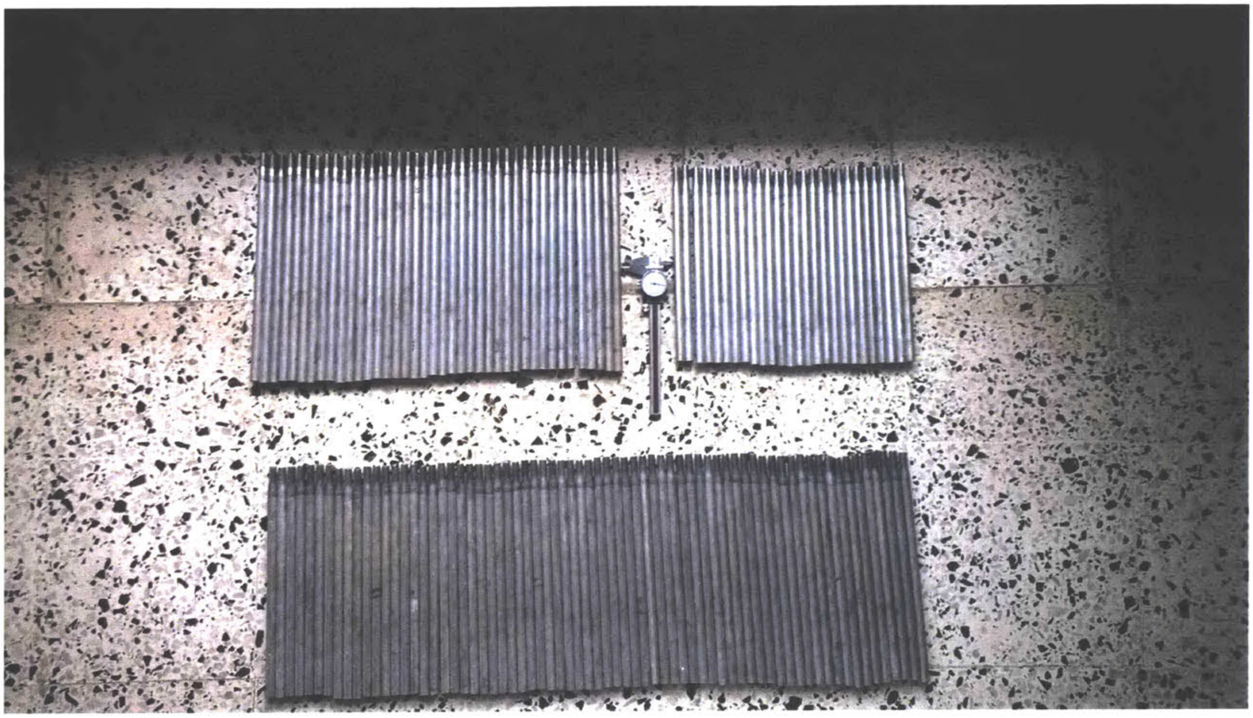


Figure 10: Pieces of the folding cane

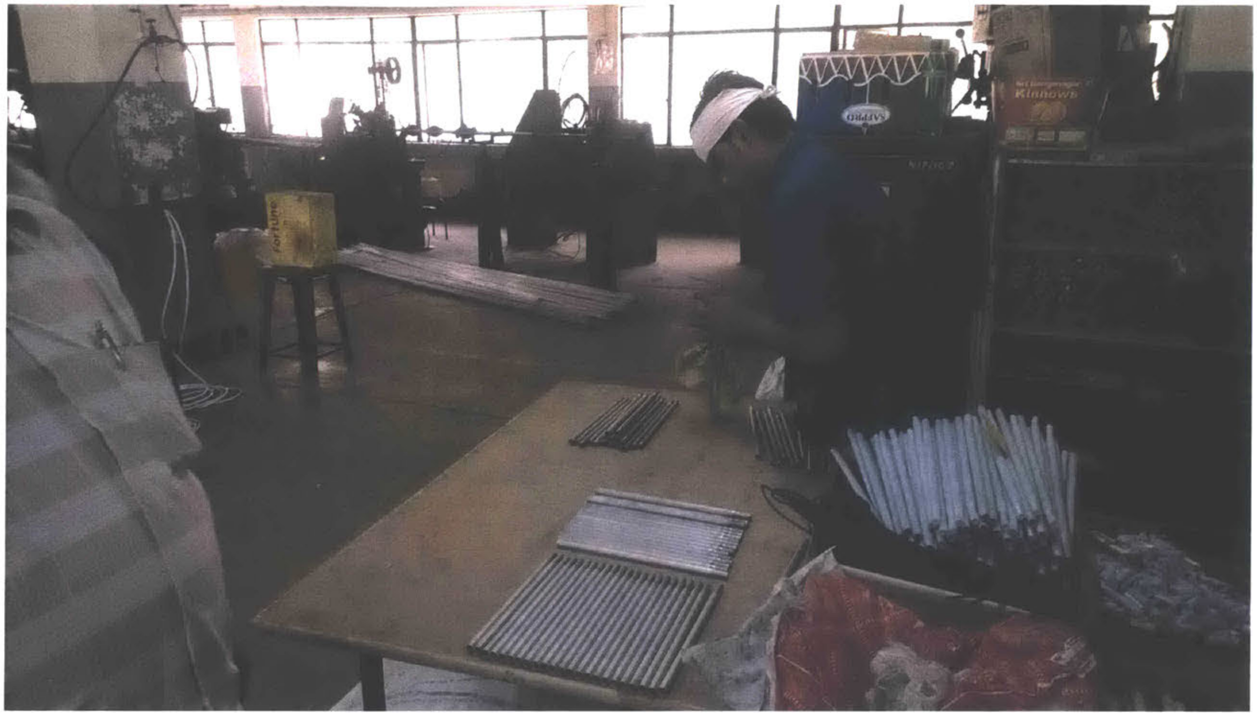


Figure 11: Manufacturing by machine operators with vision impairment

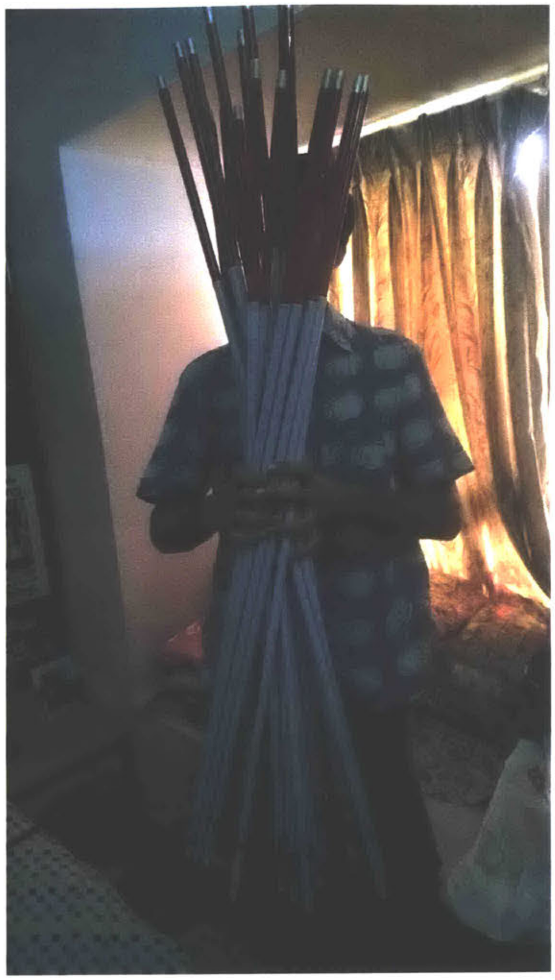


Figure 12: Some of the final products

Figure 13: The final product

Some of the features of this design over the cane manufactured at the NAB workshop were:

1. 20% lighter
2. 17% stronger at the joints
3. Required fewer manufacturing processes to produce
4. Lot more rigid
5. Safer because of reflective strips
6. Cheaper to produce
7. More user friendly because of replaceable handle and easy to change elastic.

This product received very positive reviews in field testing.

With this product, it was now possible to design for the space provided in the replaceable grip rather than designing a new cane entirely. So I started to think of all the features that such a product might have. Apart from the two electronic aids designed and tested as described earlier, some additional needs that I discovered were:

1. Problems locating friends or people a user wants to meet in crowded places.
2. At night, people on the street don't always notice them even while they use the cane which is designed to be visible.

To address these, I worked on looking at Bluetooth connectivity between canes as a means of finding other people in crowded places. This could also become a way of seeking help from strangers. I discovered this need when I enquired about aluminium tips on folding canes and people mentioned that one of the benefits of using it was that it easy to find another person with vision impairment in a crowded place by hearing the sound that the tip made on the ground. People would often tap their cane on the ground while waiting at railways stations to be able to let any other vision impaired people know that they could move together. Moving with someone else who might have slightly better vision or better skills was safer.

It would also be beneficial to have a sound and visual alert on the cane so that people would be visible in all light conditions and could use a horn to alert other people of their presence if required.

This device could fit on to the folding cane in place of the replaceable handle. It was also important that the product did not look like a health product but was attractive and desirable. I designed it to be available in several different colors.

Here are some renders of the design concept:

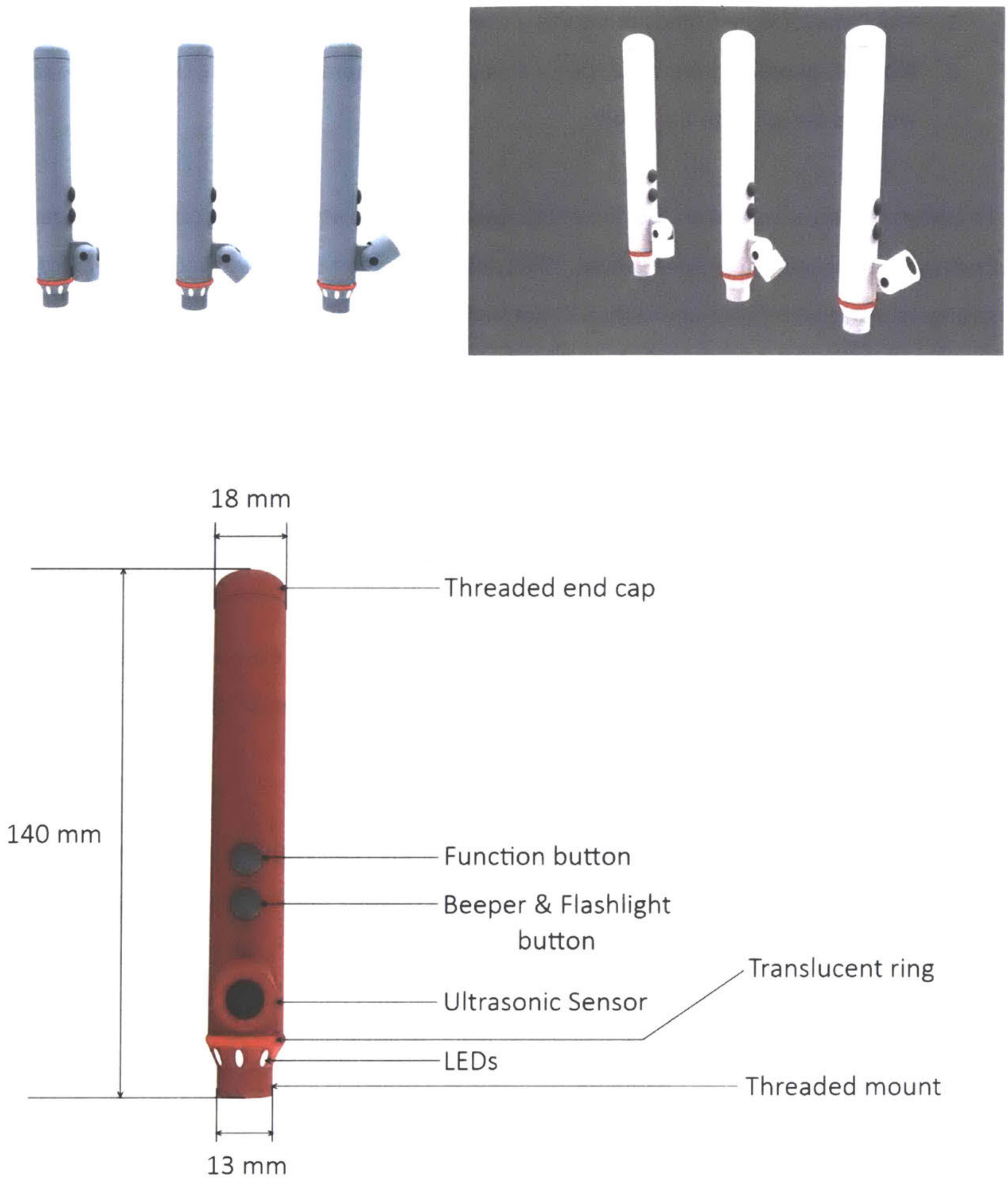


Figure 14: Renders of the design concept

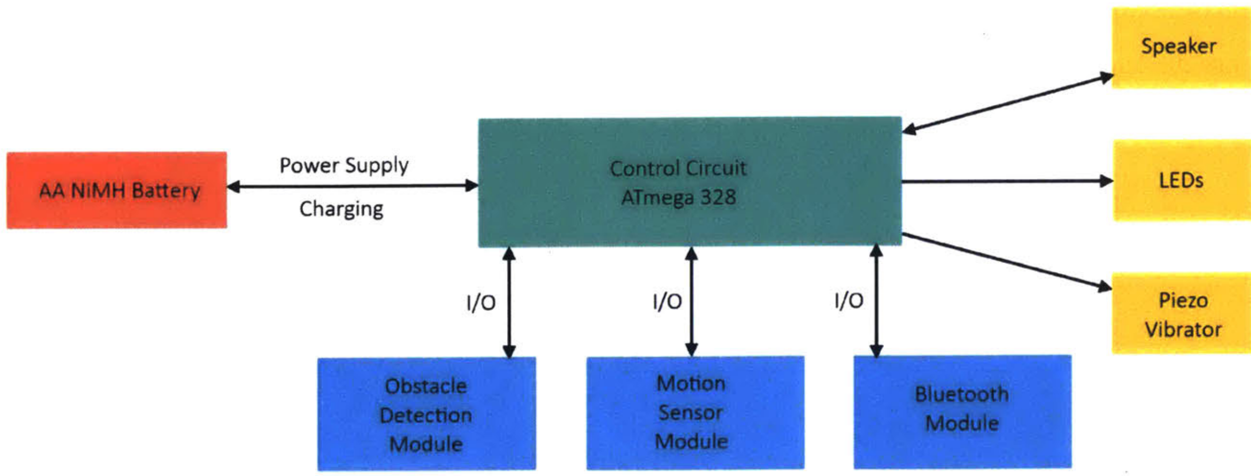


Figure 15: Product Architecture

At this point, it became clear that there were significant systemic issues involved in trying to solve problems of people with vision impairment in India and designing a product would only serve a few thousand users at most who could afford it. There are challenges in being independent, getting educated, getting work, meeting a partner, getting assistance and even with having a healthy social life. There is a large information asymmetry. Most people with vision impairment are also left behind economically. Public infrastructure is not accessible. People with vision impairment are not represented in the government. There is no law equivalent to the Americans with Disabilities Act [3] to ensure that people with disabilities in India do not face undue hardships.

There were also challenges for designers and businesses trying to work in this space dominated by NGOs and the government with not much room for social ventures. It was also difficult to independently get adequate access to people with vision impairment to work together on developing some solutions.

As the product slowly started to look like a type of small platform mounted on the cane with changeable modules, I started thinking more on the lines of what a broader platform could achieve. While still limited to the idea of a physical product, the first concept for this was a forum where designers, researchers and people with vision impairment might interact and create and share knowledge.

At this point, the project was put on hold. It was only resumed two years later as part of the spring term project for IDM.

5.5 Team

Vishal Jain who has a background in business and is very active in the vision impairment community. He is vision impaired himself.

Matthew Rosen, a classmate at IDM with a background in engineering solutions for marginalized communities.

Sagar Sodah, a web and app developer with vision impairment who is also very active in the vision impairment community.

5.6 Research Part II

Process

The research process at this stage was expanded to include various stakeholders including:

1. People with vision impairment
2. Designers and companies working on products for people with vision impairment.
3. People with vision impairment who have created solutions in this space.
4. NGOs

5. Researchers
6. Product distributors and marketplaces

Our focus at this stage was to understand the product development and distribution system and attempt to create a solution to address the problems in this system.

We started by asking some fundamental questions such as:

1. Does our project need to exist?
2. What does it need to do?
3. How does it do these things?

We then developed further questions aimed at designers, users and user innovators which we mapped back to these fundamental question. These were used to generate separate questionnaires for each stakeholder while focusing the questions to answer our fundamental questions.

fx Level

	Level	Sr. No.	Question	Primary/ Secondary Research	Stakeholders	Notes
2	A Does Apunka need to exist?	1	Is technology the solution?	Secondary		Look at the assistive tech market in the US or Europe and see what's working and why.
3		2	Is community forming (online and offline) a desirable solution?			Products that are not tech-heavy can also be generated on the platform Something like meetup? major cities have informal groups, organizing through whatsapp and facebook Vishal's marketing study, 2011 (160 respondents: technology users across India. Study conducted through online surveys and offline through NGO's and personal relationships) Study for Peerson to evaluate if there's a business opportunity for accessible printed books. Affordability was low even when need was very high. Printshare - bookshare for accessible books shared in DAISY format I-Way information sharing service Inclov social spaces: matchmaking app started offline group meetups. Talk to Kalyani Khona, co-founder
4		3	Is employment generation a part of our solution?			
5		4	Does a market for assistive technology exist? - How big is it? - Where is it? - What demographic?	Primary	U, O, C	Distribution problem? Smartphone adoption a good indicator? Literacy level, English competence could be a factor. Learning support for product use. Market research is an important service maybe. Get data from the government? census data (geographic distribution, city vs rural, age, gender, etc) Other products adoption
6		5	Are there best practices for assistive tech businesses that could have the largest number of benefits without creating unnecessary hurdles? - If so, could establishing these best practices be a good end point? - Or should they be encouraged for businesses on apunka?			Why isn't there financing for buyers? Other organizations doing accessibility consulting Kyle Keane's class
7		6	Is it difficult for users to find products that they need?			
8						
9	B What does Apunka need to do?	1	What is the biggest hurdle in product development?	Primary	D, C	Location specific research

Figure 16: Example of our fundamental questions

fx No.

	A	B	C	D	E
1	No.	Question	Overall	Notes	Comments
2		What do you think are the three biggest problems facing you and others like you?	A1/A3		
3	1	Do you think more products designed specifically for your problems would be useful to you?	A1		Context dependent
4	2	Do you think mainstream products being more accessible would be better?	A1		
5	3	Are there simple (not technologically complex) solutions to some of the problems you face and have faced in the past? How do you define simple and complex?	A1		UX defines simplicity
6					
7		Have you ever bought any assistive tool or technology products?	A4		
8		How did you decide whether to buy?	A4		
9		What were they?	A4		
10		What did they cost?	A4		
11		Where did you buy them from?	A4		
12		How useful were they to you?	A4		
13	4	How did you find out about them?	A4		
14		Do you know others who use the same products?	A4		
15		Do you think other people like buying such products?	A4		
16					
17	**5**	**How many other people do you know who have the same disability?**	**A2**		
18	6	How did you meet them?	A2		
19	7	What is your level of closeness with them?	A2		
20	8	How often do you meet them?	A2		
21	9	What kind of conversations do you have with them?	A2		
22	10	What do they do?	A2	Establish how external factors like employment, financial status, age etc affect their relationships	
23	11	How old are they?	A2		
24	12	What are your current means of communication with them?	A2	Whatsapp, Facebook, Phone, meeting physically	
25	13	Would knowing more people be beneficial to everyone?	A2	Establish how much the community values these ties and in what respect	
26					
27	22	Have you ever spoken to anyone designing an assistive tech product?	B2		
28	23	Has anyone you know ever spoken to anyone designing an assistive tech product?	B2		
29		What are your primary motivations for talking to people designing assistive tech products?			
30	24	Would you be interested in talking to people who design assistive tech products?	B2		
31	25	Do you have ideas for products that you would find useful?	B2		
32	26	Do you discuss ideas you have with people you know?	B2		

Figure 17: Example of some of the questions on the questionnaire for users mapped to fundamental questions

Our first major assumption was that increasing technology adoption by people with disabilities would result in better preparedness in addressing their problems and therefore lead to more independence. Further study of systemic issues revealed that the lack of technology adoption could be boiled down to: 1) Market Challenges and 2) Design Challenges.

Market challenges involve the inefficiencies in the supply chain of assistive tools and products due to a fragmented market. There is currently no single marketplace for assistive products in India. This makes it very difficult for existing products to get distributed and thus the supply is significantly lower than demand. Coupled with high barriers to entry due to reliance on a few large NGOs, new products face large difficulties in entering the market or achieving scale resulting in few options for people with disabilities.

Design Challenges involve the usability and quality of assistive products that do make it to the market. A lot of the users interviewed found that the quality of assistive products that they used was not at par with the mainstream products that they used. Interviewing companies who had assistive products in the market gave us more insight on the difficulties faced by them. There were issues with carrying out enough research, having all the skills and resources required to build the product and to be assured that the product will sell and achieve scale.

Designers expressed that they did not design they would find it useful to have more research subjects and more interaction with people with disabilities but once they had developed a product and had some customers, that need was satisfied. There were issues with bringing products to market because of a fragmented supply chain.

We learnt from online marketplaces in the US that they marketed and distributed products for mostly small companies. The companies were founded in most cases by people close to people with disabilities or people with disabilities themselves who recognized needs and built products to address these.

Overall, we felt that the existence of fragmentation in product delivery, information delivery and society was responsible for the lack of independence and social mobility of people with disabilities.

There was no unified marketplace for assistive products in India. There were some large distributors who were NGOs. Popular e-commerce platforms did not sell assistive products (See Appendix). NGOs did not sell online. People had to order their products over the phone or buy them in person. Moreover, none of these websites or services were very accessible in terms of their UX (See Appendix).

Concepts

We came up with several concepts that could satisfy the various needs. These are illustrated below. We condensed this into two concepts, a marketplace and a design tool.

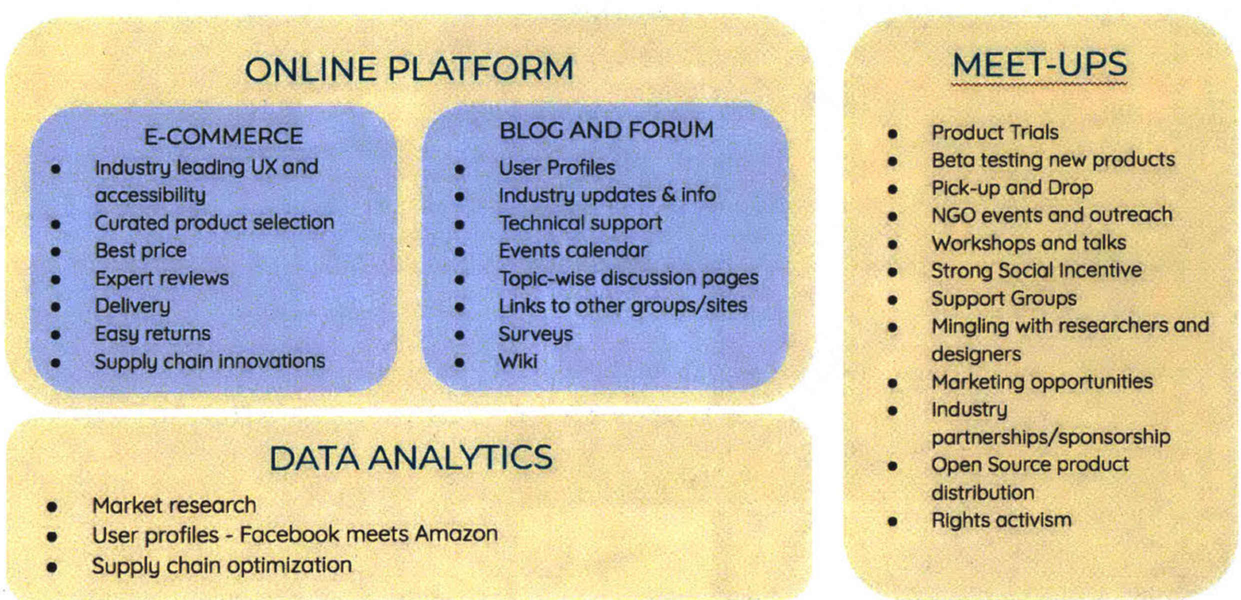


Figure 18: Encapsulation of various concepts

This was used to generate three separate concepts which are described below.

Concept 1: Marketplace for Assistive Products.

The marketplace concept is an e-commerce platform which lists all products available from all distributors across India: NGOs and businesses selling and distributing assistive products. The business would start by providing fulfilment services to existing players in the supply chain since there is no online platform that they currently sell through. Users would benefit by having a one-stop shop to buy all the products they need with an accessible UX that's easy to navigate.

The concept required designing a website which has an easy to use and accessible user experience along with physically setting up the supply chain in collaboration with existing distributors and sellers.

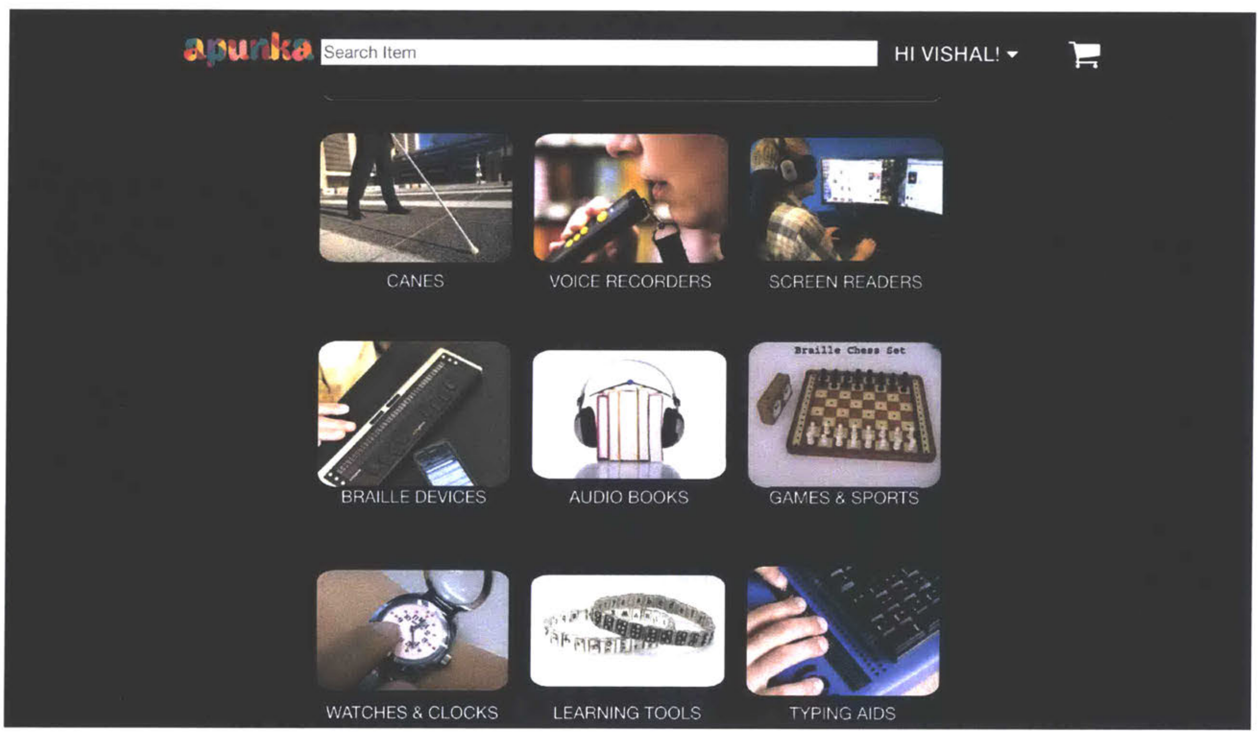


Figure 19: Marketplace website layout in high contrast mode

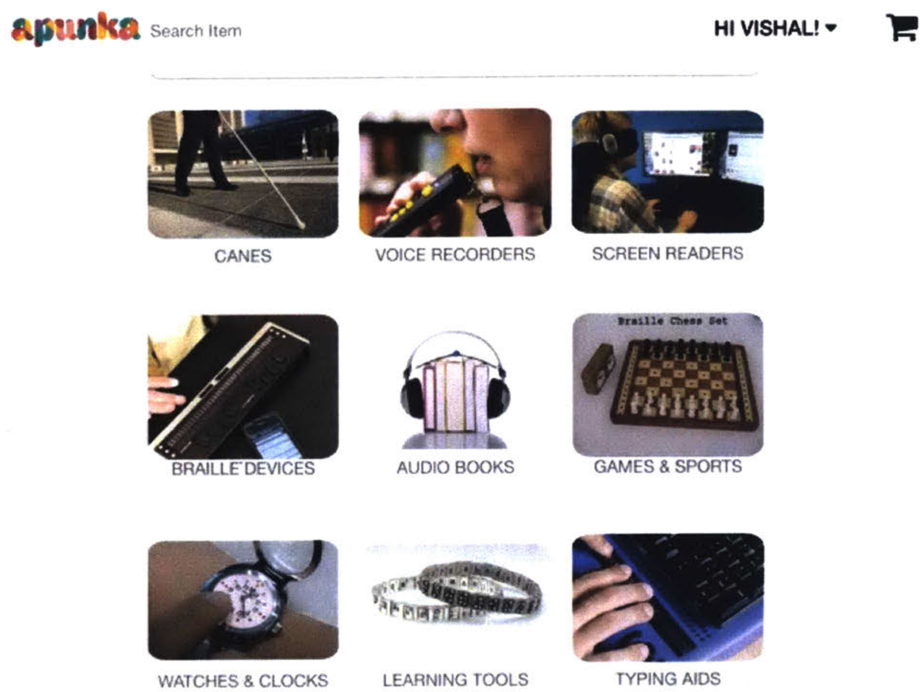


Figure 20: Marketplace website home page

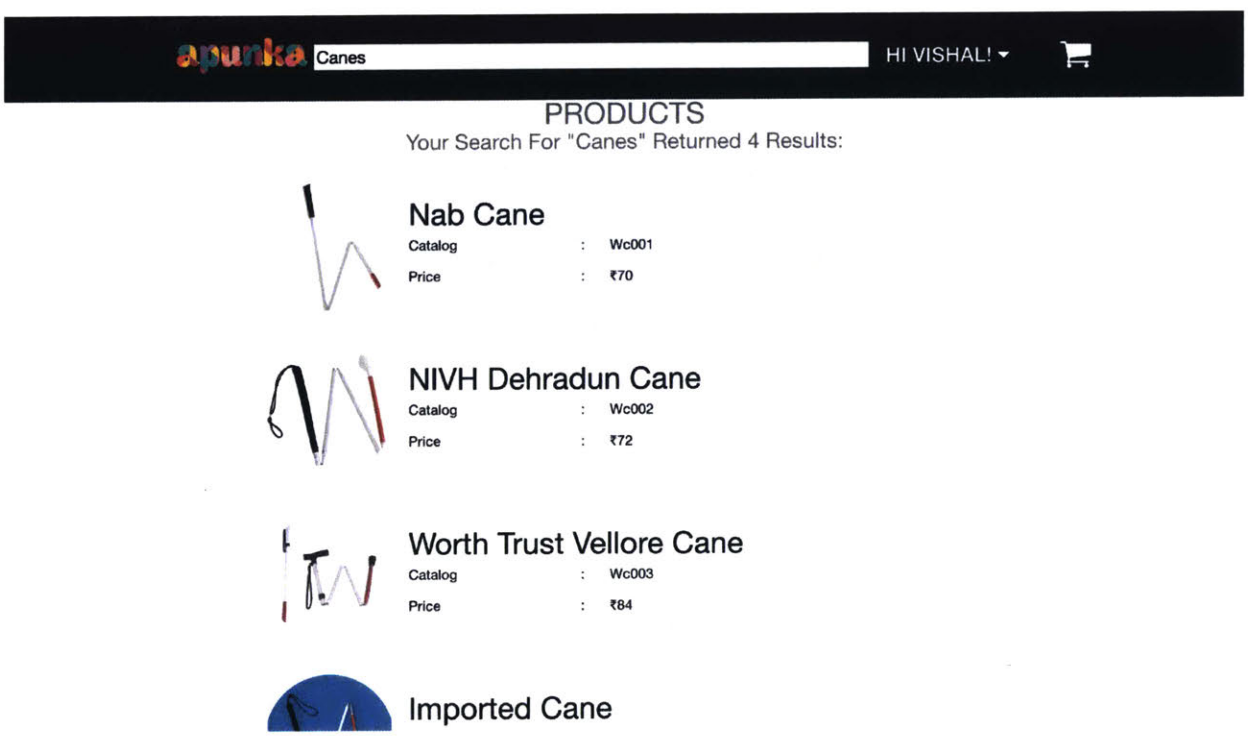
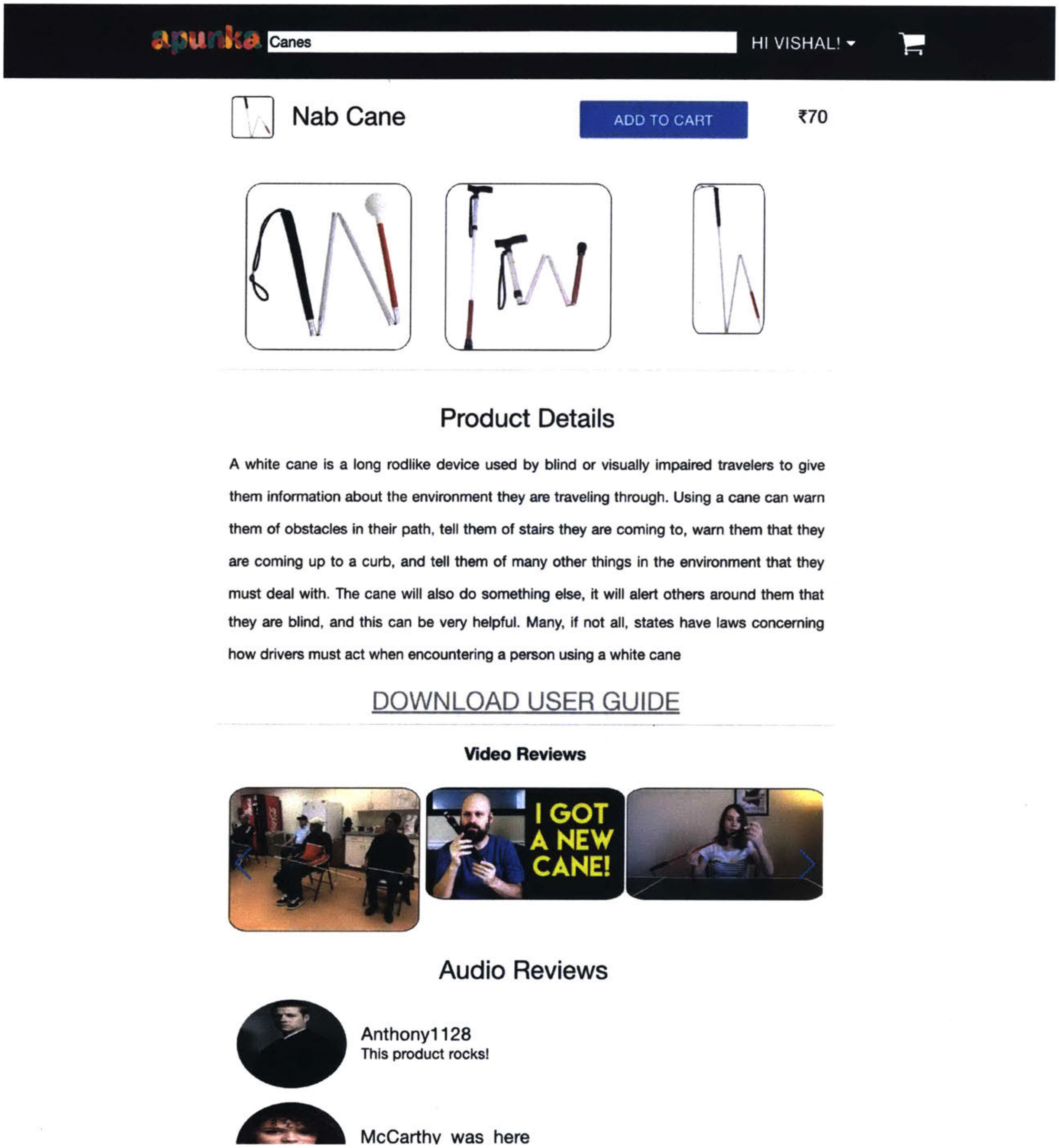


Figure 21: Product listings page


apunka
Canes
HI VISHAL!
Nab Cane
ADD TO CART
₹70
Product Details
A white cane is a long rodlike device used by blind or visually impaired travelers to give them information about the environment they are traveling through. Using a cane can warn them of obstacles in their path, tell them of stairs they are coming to, warn them that they are coming up to a curb, and tell them of many other things in the environment that they must deal with. The cane will also do something else, it will alert others around them that they are blind, and this can be very helpful. Many, if not all, states have laws concerning how drivers must act when encountering a person using a white cane
DOWNLOAD USER GUIDE
Video Reviews
I GOT A NEW CANE!
Audio Reviews
Anthony1128
This product rocks!
McCarthy was here

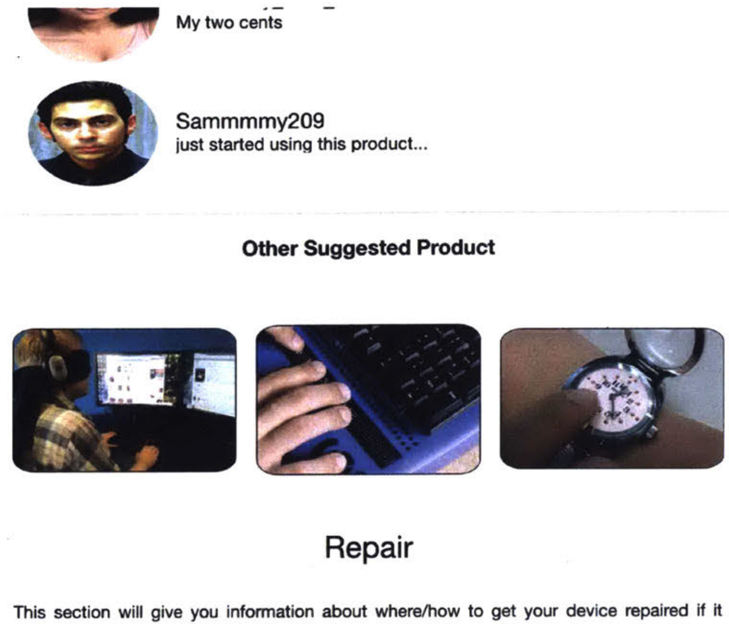


Figure 22: Product description page

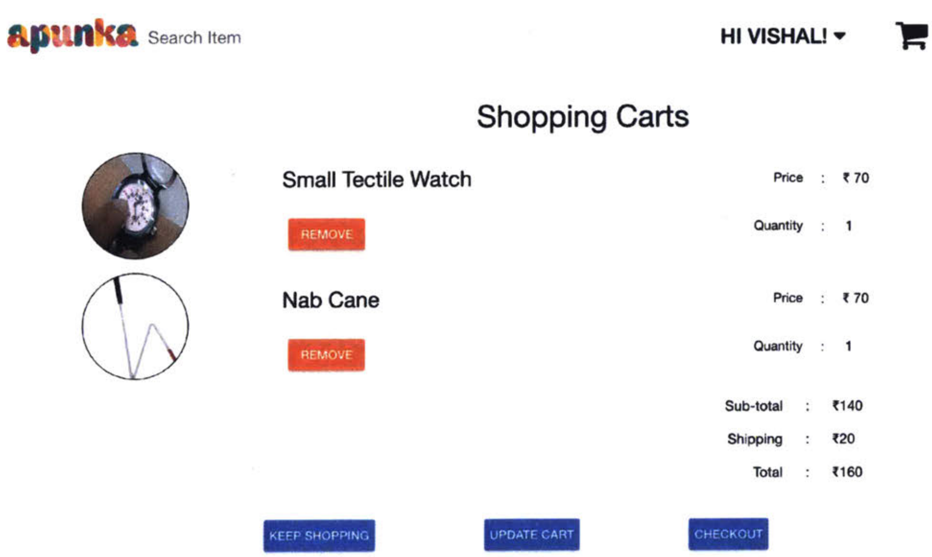


Figure 23: Shopping cart page

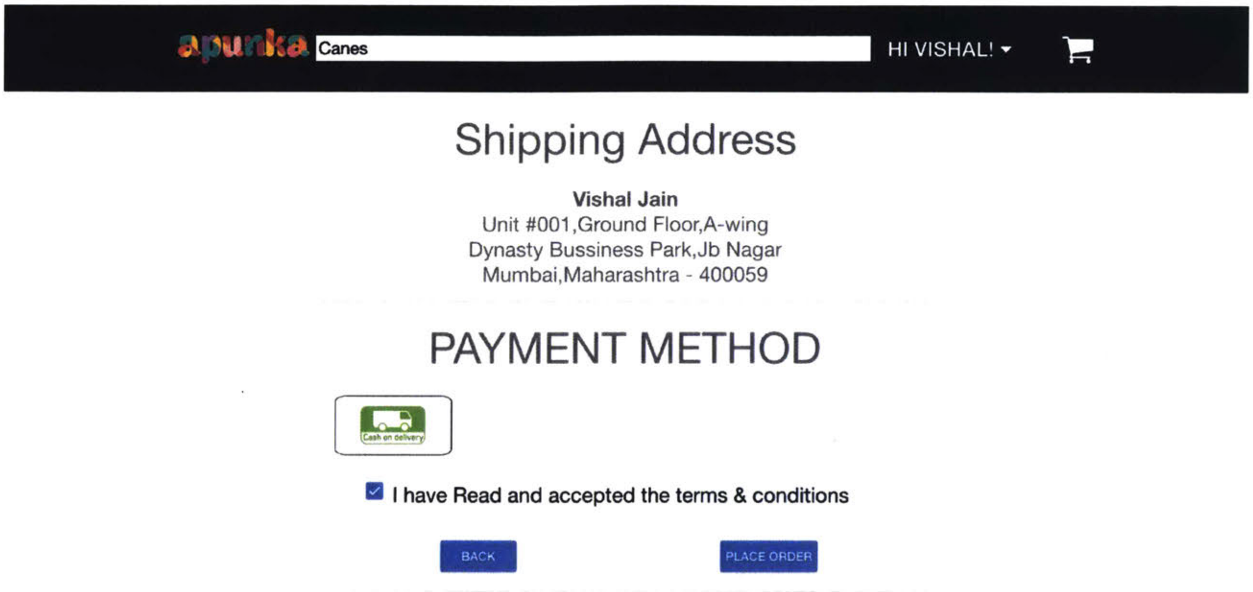


Figure 24: Payment page

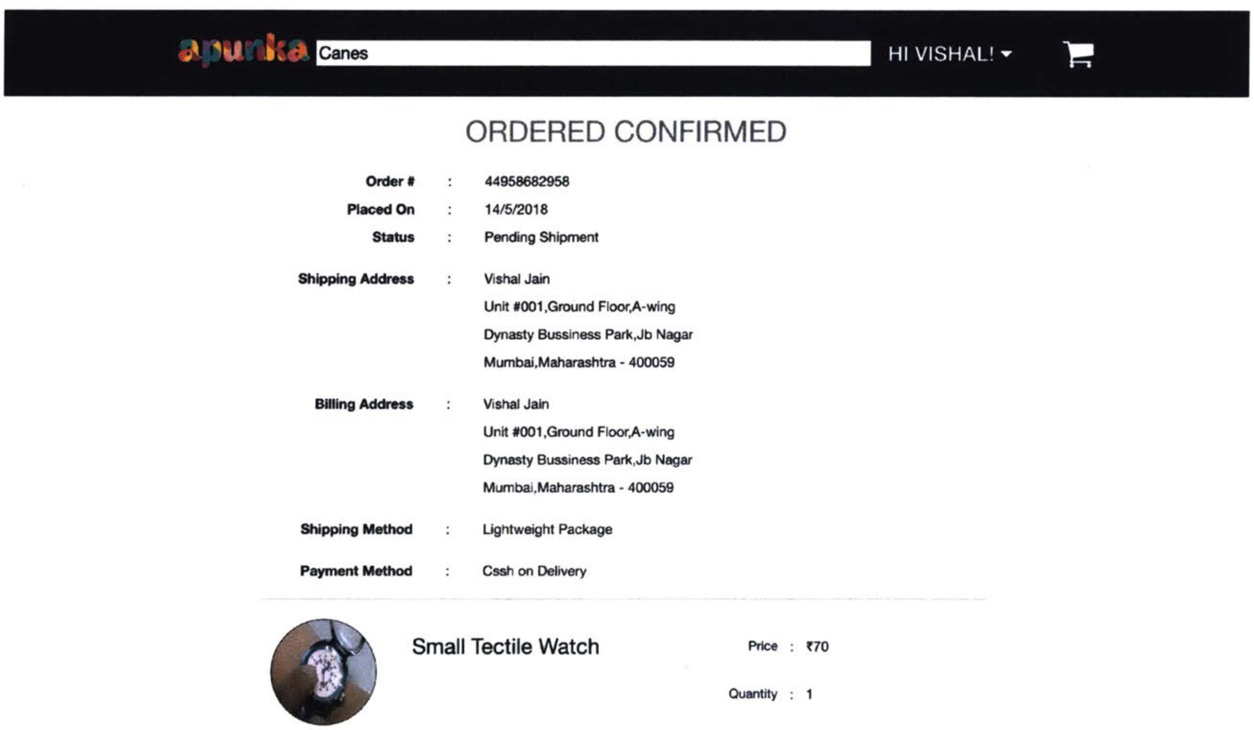


Figure 25: Order confirmation page

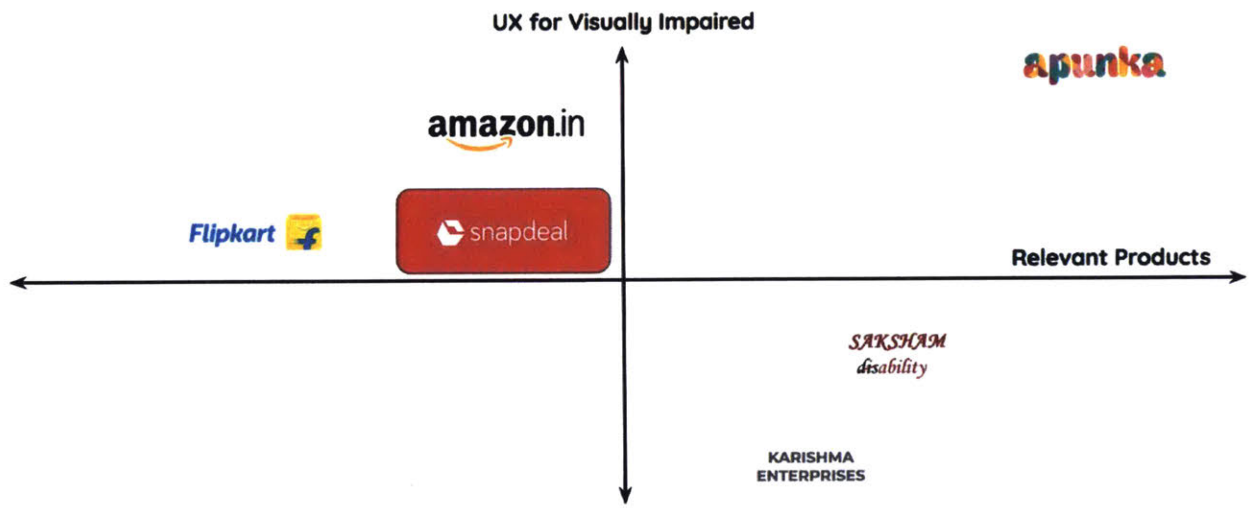


Figure 26: Comparison of our product with existing marketplaces

Concept 2: Design Tool for Designers of Assistive Products

To address the second part of the problems we identified, the design challenges, the concept that was developed was a design tool to help designers design better products. It consisted of a mechanism to provide access to users for research, access to resources, guidance and people to build the best possible product and access to the network of distributors to ease the distribution and sale of products.

DESIGN TOOL

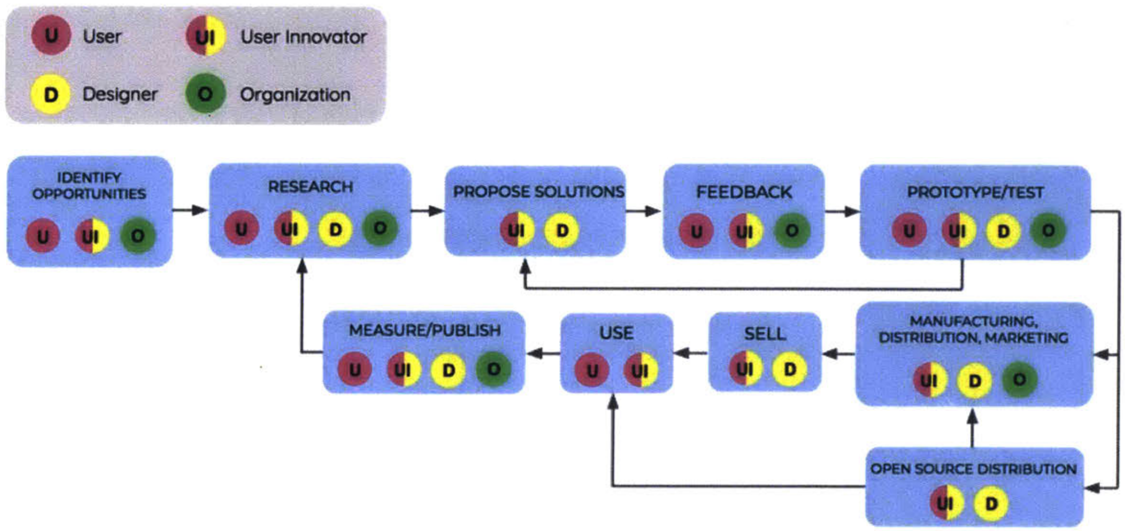


Figure 27: Design Tool workflow

At this point, we realized that while these concepts were necessary, they were insufficient in solving the larger issue. Peak technology adoption may still leave a lot to be desired. We then started looking at the problem related to information which play into all realms like service delivery, education, social life and health. This problem had two layers: accumulating the right information and providing easy access to it.

<u>Concept 3:</u> Forum

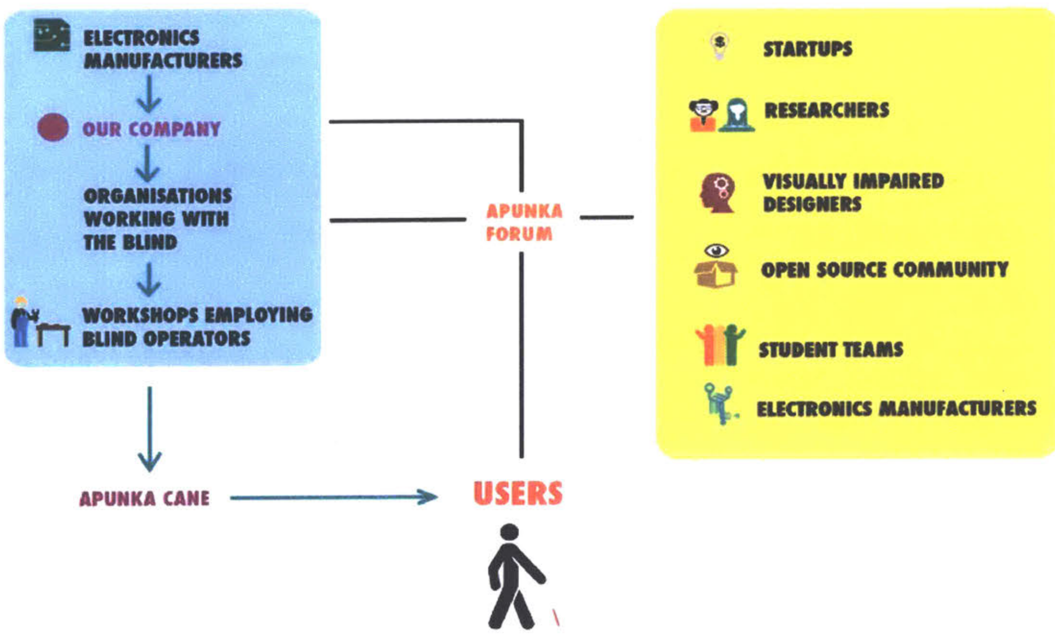


Figure 28: Forum Structure

This concept was developed to accumulate the relevant information. Currently most discussions among people with disabilities online are limited to email lists and Facebook and messenger application groups. These are either badly organized or contain large quantities of irrelevant information. There is no place for generation and storage of purposeful content and sharing content from other sources. Although not novel, the forum would serve this purpose very well. It would even solve for the problems the first two concepts hoped to solve.

While accessible UX would make it easy to use the above concepts, we felt that it limited the access to this information to computers and smartphones. We felt that we needed to look further and create a solution that would last and is technologically feasible.

5.7 Research Part III

The third phase of research involved taking the concepts to the various stakeholders and getting feedback. This was not only to pick between the concepts but also to understand the system more thoroughly.

We got the most pertinent feedback from NGOs. We learnt that NGOs were not concerned with the commercial aspects of product distribution and all of them sold products either at cost or at a loss. They were concerned with having greater outreach and bringing their services to more people. The primary goal was greater outreach and better service delivery.

We also realized that most of the information that was relevant to the stakeholders was not available online or was difficult to find. User generated content, though useful, would not cover everything and would leave a lot of information out. NGOs were focused on outreach and it seemed like they would be a great way to get content online and incentivize this by generating outreach for them.

We also felt that having an accessible UX, while useful was not the best possible option available. The future we could envision used AI assistants and voice or text interfaces for natural conversations to provide information and assistance with various tasks.

Concept and Future Work

The current concept is an AI assistant that can be an app on Google Assistant, Alexa or Siri. This app gets its data from an underlying online ecosystem which is designed for NGOs to increase their outreach. It consists of a platform for NGOs to upload their information and announcements. It also has a section for users to upload information. The assistant draws from information already available online and on email lists and web and social media groups of users and makes it available to everyone. The assistant will be accessible by phone as well since most people with vision impairment do not have smartphones yet. It will identify users based on their phone numbers or voice to continue to provide personalized service and gather data to create a more detailed profile. The assistant will have access to health data unlike mainstream assistants and therefore be in a better position to provide accurate information which is specific and important. It will be available in many regional languages.

The assistant will also be paired with the marketplace so people can easily purchase products they need. It will streamline the product, service and information delivery systems for this population and by doing so, we hope it solves several problems of access, independence and well-being.

Some possible scenarios are outlined below:

"There is an upcoming workshop on mobility training in locality X close to your house. Would you like me to register you for it?"

"It's been 6 months since you changed the elastic band in your cane, shall I order one for you?"

"The way to enable that feature in JAWS is xyz."

"49 out of 54 people on the forum said that restaurant X is accessible and friendly. Shall I go ahead and book a table for two?"

"I do not currently have the answer to that. Let me ask that question to the hive-mind and get back to you."

We are currently working on developing this concept.

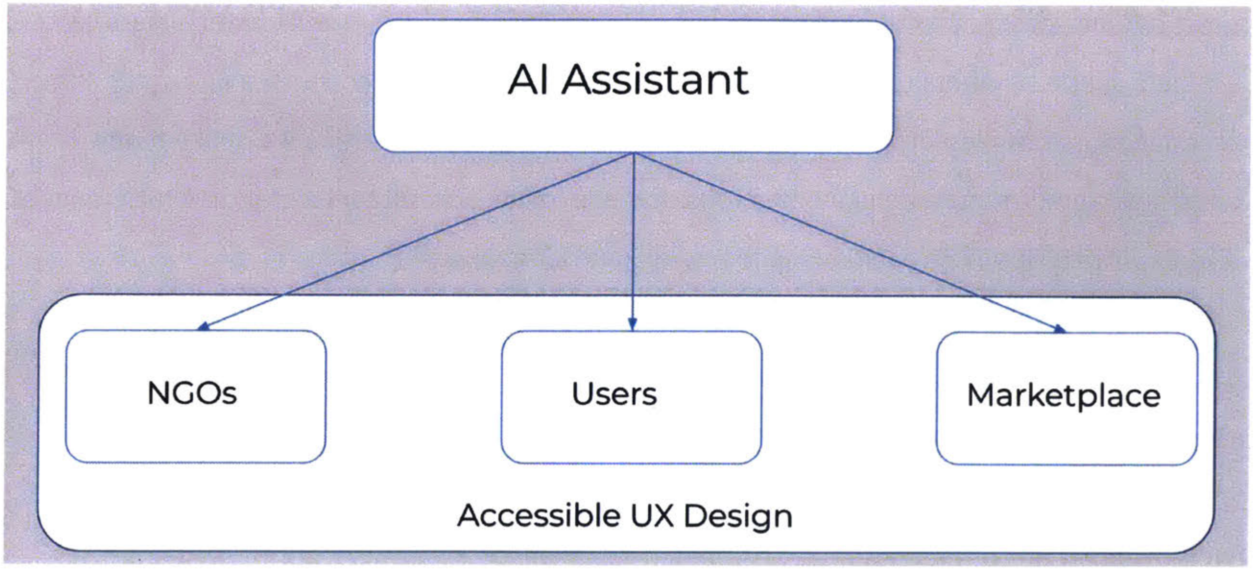


Figure 29: Layout of the AI Assistant concept

5.8 Design Framework Learnings

1. When a product is a complex system, it must be approached as such. The scope and boundaries should be worked towards and arrived at from research. There may be several available solutions of smaller scope which may then seem insufficient but this is more likely to happen due to oversight.

2. Complex system design frameworks available may be used towards building such systems. Important considerations are to ensure that there is minimal coupling and dependencies and the system is not unnecessarily complex.

3. Researching will reveal unknown stakeholders or change the importance of stakeholders relative to each other. Concept and business model testing is an important way of

discovering leverage capacities.

4. Working with someone embedded within the system is a very useful way of discovering latent needs and intricate details which are easy to overlook. It is more likely to lead to a successful solution.

5. It is tempting to completely redesign a system but complex systems possess a lot of inertia and are slow to change. It is important to recognize this and have a plan of initiating change in phases on different components of the system. It is not useful to try to reinvent the wheel and design parts of the system which don't need to be re-designed. The design should be adaptable and flexible.

6. Creativity and intuition are valuable forces while working with complex systems. They should not be underestimated. This may apply to redefining the roles of some component of the system or completely design new components.

7. Solutions designed for one component of the system will often reveal problems in other components. It is important to not lose track of these.

8. The user is just one of the stakeholders. A complex system serves the requirements of various stakeholders and all must be taken into consideration. Stakeholders often have competing requirements in which case the design philosophy or envisioned future states are useful to decide priorities.

9. Business and engineering requirements must be taken into consideration from the onset to ensure that the system being designed is sustainable and won't implode.

10. Questioning all assumptions down to the most fundamental and verifying them ensures a strong foundation. It is easy to believe that some approach may be better than

another (for example, a top-down approach vs a bottom-up approach) but these are highly contextual and should not be used as principles.

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Chapter 6

Proposed Preliminary Framework

Based on the insights gained from going through several iterations of the design process and the case studies, I propose a preliminary framework for product design and development when there is a systems component involved. This framework states that there is no template for the design process that can usefully be followed to design complex systems. Rather, a designer must have a large arsenal of tools to work with and use their discretion and the requirements of the design process to decide which tools to use when.

I describe this process below in the different phases although that is not to suggest these phases are sequential or tightly bounded. I work with the user-centered design framework as a way to highlight changes.

The overarching theme is the broadening of the different phases spatially and temporally.

Spatial broadening involves broadening of the scope of the research, the breadth of the subjects, stakeholders and associated systems, the variety of ideas and possible systems, the breadth of the impact of the proposed design, the scale of implementation and its impact at large and small scales and finally, analysis of similar nature post product launch.

Temporal broadening involves studying historical factors wherever relevant to understand the path of the system and the sensibilities of the people involved, to simulate and analyze future states of the system due to the proposed design and to continue analysis and improvement after product launch.

Though mentioned separately here for clarity, these two ideas go hand-in-hand and most analysis is a function of both ideas. Moreover, these processes often overlap and go back and forth as the design process progresses.

6.1 Research Phase

The first stage of the design process involves understanding the needs of the various stakeholders (not just the users) and understanding the system one is trying to work with.

The important differences here are that multiple stakeholders are identified and worked with since no single stakeholder has a complete vision of the entire system. The entire system around or with the product is studied and understood. The positions and angles of the various stakeholders are taken into account to place their needs into context. This not only creates a better understanding of the entire playing field but reduces the biases brought by designers to the design research process, the foremost being the tendency to be solution-centric or narrowed by the capabilities the designer has to offer.

The historical background of the system and stakeholders is studied wherever relevant to better understand positions and trends and weigh these more accurately. Systems associated with the system under consideration are studied to identify any possible symbioses. Analogous systems are also studied to broadly understand the dynamics and gain insights on possible outcomes.

This is in stark contrast with the user-centered design process for the breadth of the research and the focus on multiple stakeholders to understand system requirements along with product requirements (with varying levels of overlap between the two). The timelines involved in this are also extended.

6.2 Design Phase

This phase involves decisions related to the design direction, the generation of concepts and prototyping. The spatial and temporal expansion becomes much more pertinent in these stages.

The design direction is the most important decision in the process. This is where the designer expresses their opinion about how they understand the project at hand and where they believe it should go. This is formulated based on the findings from the research stage, a broader understanding of the research area and where they see it going and most importantly, with the vision of the designer and the mission of the organization involved. Many future decisions may be resolved based on how congruent they are with the design direction. The design direction must be chosen carefully and with the best possible understanding of the large scale outcomes.

Concept generation can then be pursued keeping this in mind. There are several paths to the goal that can be explored and formulated into concepts. The concepts may have multiple pieces and multiple phases of development. The development of the concepts themselves involves various permutations of the available parts of the system and the proficiency of the designer and the implementing organization. The angles and leads gained from research can be arranged in different ways to arrive at a resultant solution that satisfies the primary goals of the design project. This is also the stage that requires the most amount of creativity.

The designers must then evaluate their concepts based on thorough analysis. This includes playing out multiple scenarios, simulating for how concepts behave at scale (firstly, how the system and product would interact with each other and the rest of the world once it is at scale and secondly, how it behaves once it's beyond the intended scale for example if everyone on the planet was a user) The simulations should be played out into timeframes well beyond the scope of the designer to evaluate how sustainable the concept is. Tools like System Dynamics and the Axiomatic Design framework are very useful at this stage. It is important to avoid the possibility of 'unintended consequences' and policy resistance at this stage.

It is important to realize that it is nearly impossible to follow a template when working with complex systems and each problem must be approached in a unique way. A case-by-case approach is necessary. Analogous systems are useful in predicting some outcomes and accounting for them but cannot be relied on heavily. It is useful to start broad and then narrow down while looking to identify possible connections and symbiosis between different parts of the system.

While prototyping, it is important to ensure that the high leverage decisions are reflected in the prototype. An entire system may not be possible to prototype at a small stage in which case simulation results are helpful in imitating future conditions based on the current understanding. This experience is important to design the phased roll-out of a pilot where relevant. This stage should be perceived not as an output of ideas but rather as an experiment design.

The testing stage is useful to gather data both on the performance of the prototype and the understanding of the system. The reactions to a prototype and data from its use provide insights also on gaps of knowledge and basis of assumptions in the functioning of the system. Multiple iterations between this stage and the concept stage may be necessary before a final prototype is designed.

6.3 Implementation and Post-Launch Analysis

The job of a designer does not end after designing the project. This is necessary both for improved design over time and for pinning responsibility. This is a process that occurs already when a project is rolled out in phases.

During implementation and post-launch, analysis should continue to establish that the product is behaving as intended. New insights into the structure of the system gained from its behavior from interacting with the product should be incorporated into the design. Path dependence is a large factor to be kept in mind as the project progresses. Assumptions must be re-validated or updated at this stage.

6.4 Philosophy

The framework is centered around the designer and the designer's experience as they go through the process of designing a product and system.

It breaks down the activities of the designer into two broad categories: Understanding and Creating, that the designer must cycle between constantly as the design process progresses. All the steps in the design process can be segregated into one of the two categories. Analogies of these categories exist such as analysis and synthesis, and input and output.

Understanding consists of:

1. Research and analysis of research
2. Insights gained through simulations
3. Insights gained through testing
4. Insights gained through product launch

Creating consists of:

1. Redefining the roles of existing components
2. Rearranging existing components

3. Conceptualizing new components

The process is not broken down chronologically. Rather, its cyclical and nested nature is highlighted. The steps that a designer must follow remain the same for all design projects, namely, research, conceptualization, testing and realization of the product. These steps have different sub-steps and different tools associated with them and the designer must use their discretion to decide which of these is appropriate for the particular design process.

While the designer must carry out both Understanding and Creating throughout the design process, the magnitude of each changes as the process progresses. The earlier stages are heavier on Understanding and the later stages are more inclined towards Creating.

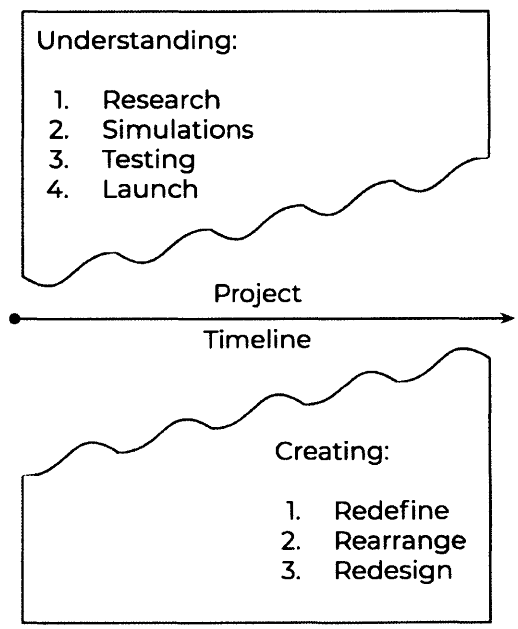

Figure 1: The varying amounts of Understanding and Creating through the process

The designer must live within the constant juxtaposition of input and output, the large scale and the small details, the present moment and everything before and after it, all simultaneously.

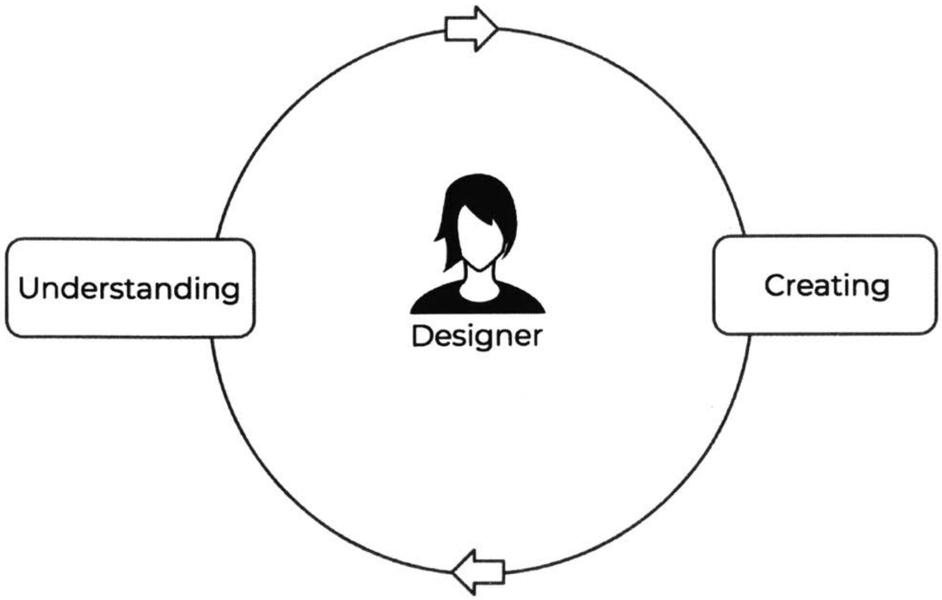

Figure 2: The cyclical nature of the design framework

The designer embodies the design framework to the extent where it can become a way of life.

6.5 Notable Features and Differences

1. The premise of the framework is that there is no template or set process for designing products with a systems component. Each case must be evaluated for itself and the design process adapted for it. The designer must have an arsenal of tools to choose from and apply based on their discretion and understanding.

2. The proposed framework separates design from the research phase. Research must be conducted independent of solutions in the beginning. Solution-centricity relies on assumptions and introduces biases which become detrimental to the goal of achieving a useful solution.

3. It advocates long-term and large scale thinking and argues against short-term solutions which are more likely to cause 'unintended consequences'. This applies to the research stage, the concept development stage and continues into the period post product launch.

4. It reframes the design process in terms of the design experience and capabilities of the designer. The process for designing for products with a systems component is highly iterative and impossible to codify chronologically. The iterations not only help with testing solutions but also reveal more information about the system which may require large changes. Each design process is as unique as the product. The only constant is the cyclical nature of the process with the designer constantly shuffling between understanding the problem and creating solutions.

5. It highlights the juxtaposition of scales and the opposing roles the designer has to play simultaneously through the design process.

6. It advocates for the setting of a design direction or design philosophy which is based on first principles and formulated after thorough examination and evaluation of all assumptions down to the most fundamental. This is helpful in preventing appropriation of any approach as a universal principle.

7. It stresses the importance of creativity and intuition even while working with complex problems and complex systems. There is scope for the engineered and the artistic both.

8. It argues against simplifying problems and simplifying evaluation methods for concepts and solutions. Complex systems require complex processes and these must be diligently performed.

9. It redefines the role of the designer as an expert investigator, creator, negotiator and visionary.

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Chapter 7

Conclusion

7.1 Future Work

The framework described earlier requires that the role of the designer be reframed as well. The designer cannot carry out a process of this nature without a mandate and must have a leadership role within the organization to be able to make the decisions required. The role of the designer can be described as consisting of the following:

1. Abstract Thinking – A designer must be the person driving the process, ensuring that it is covering everything required, is thorough, rigorous and logical. The designer must also ensure that the parts of the process are well aligned and the various pieces of research are understood in the right context. The designer is also responsible for the ethics and values associated with the project.

2. Subject Matter Expertise – The designer must come into a project with a sufficient understanding of the field of work and how it fits into the larger picture of society. The designer must be able to learn more about their area of work as the project progresses and not rely entirely on their abstract thinking abilities or discount the details of any project.

3. Skills – The designer must have the skills to conceptualize and test a project but also understand the skills required to implement it. The designer as a leader must also have the skills needed to lead a project and a team of people with diverse backgrounds.

The field of design must adapt and evolve to changing social conditions. The products we use are getting more complex over time and consequently, the role of the designer must change to ensure that at best, the products are most useful and beautiful and at worst, the products do not damage society because of the oversight or incompetence of their designers.

Parallels exist in the field of urban planning. Urban planning as an activity has gone on for millennia but did not become a formalized profession until the 1920's in the US when the first program in urban planning was offered. As cities and city systems became more and more complex, the field had to adapt and recognize that its role was complex and dynamic and its practitioners needed to be trained for that.

Design education must therefore broaden to adapt to the new reality of the product and system space as well. Designers must be trained in more than just the design process and processes associated with generating concepts and evaluating the design at various stages or with only the skills required to develop the project. Design education must expand to serve the new role the designers must now play.

- Abstract thinking includes critical thinking, ethics and philosophy apart from training in the design tools and thinking.

- Subject matter expertise requires some knowledge of history, anthropology, sociology and economics.

- Skills include knowledge of engineering, business, prototyping skills, leadership skills and team management skills.

The personal development of the designer must also be an important goal for design education instead of focusing entirely on skills. Integrated design curricula provide a strong foundation to develop such a program.

The next steps for the framework itself would be to test through controlled experiments the various parts of the framework.

7.2 Reflections

Complex systems are generally associated with rigor, methodical thinking and data-driven decisions but there is still a place for intuition, creativity and beauty in designing systems which is impossible to codify. The design of the individual parts and how different parts may interact allows for many opportunities to be creative and inventive. I would like to stress that this is strong factor in any design project but cannot be part of a framework since it is so difficult to quantify. It is my understanding that great designs are a function both of understanding the project and making decisions based on research while also being creative and relying on one's intuition. Great architects are a wonderful example of this idea. This is what made the thesis so difficult to work on since I constantly hit this wall where it seemed like there was no framework and it was futile trying to define a process or a person when there was no archetype to go by.

The truth it seems can simply be explained by the idea of being creative and well informed. One may spend a lot of time conducting research and testing different ideas but when it comes to the final product, it is often the designer and their chosen tool of expression and some moments of clarity. The final product may not always be a piece of art, but the process of realizing it is an art form.

I would like to end my work with a few lines I wrote that talk about this idea to highlight how important it is to me.

I walk the cold rough earth outside, day and night
To know why I should be with her
And when I'm locked with her inside her house
I just be.

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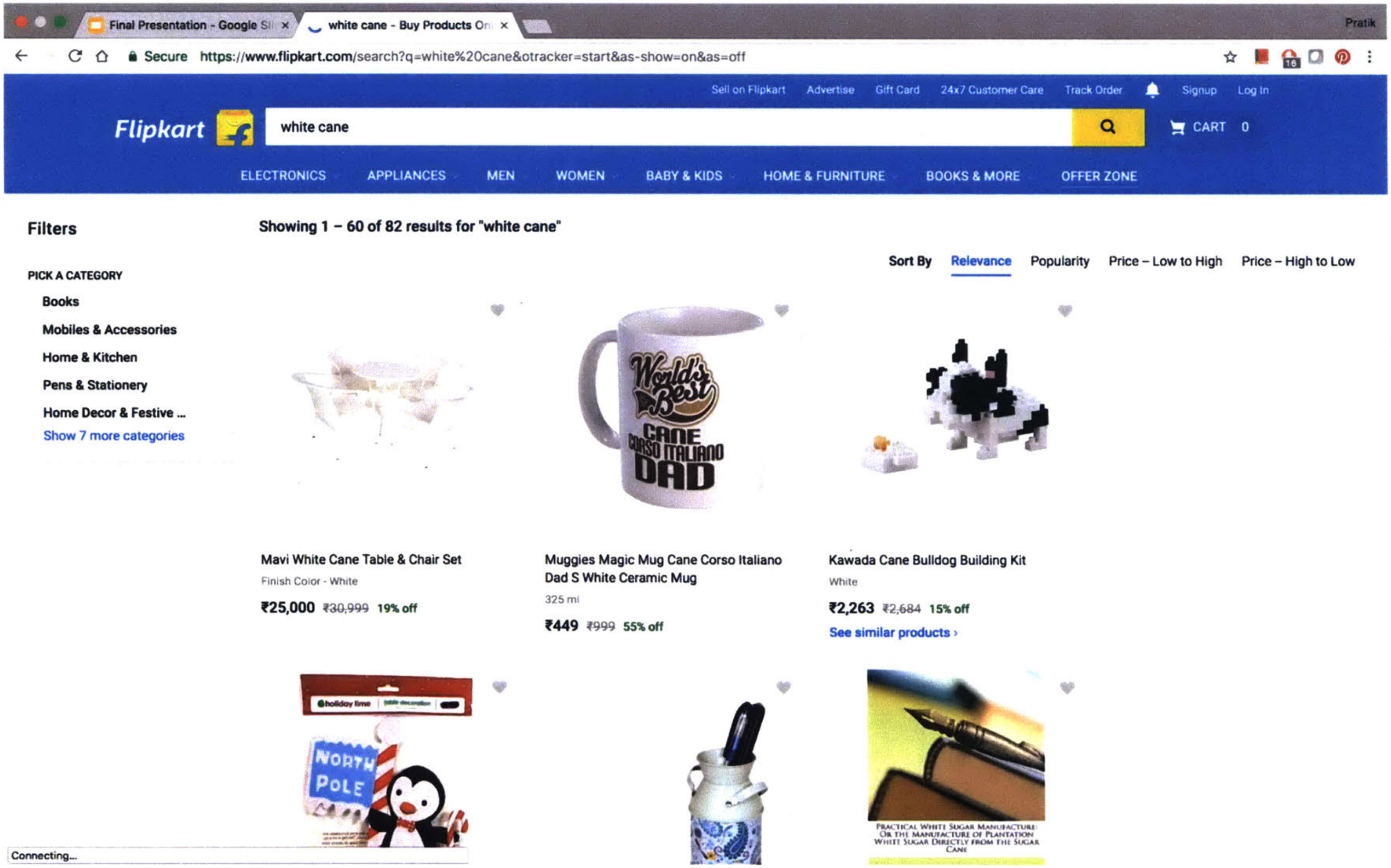
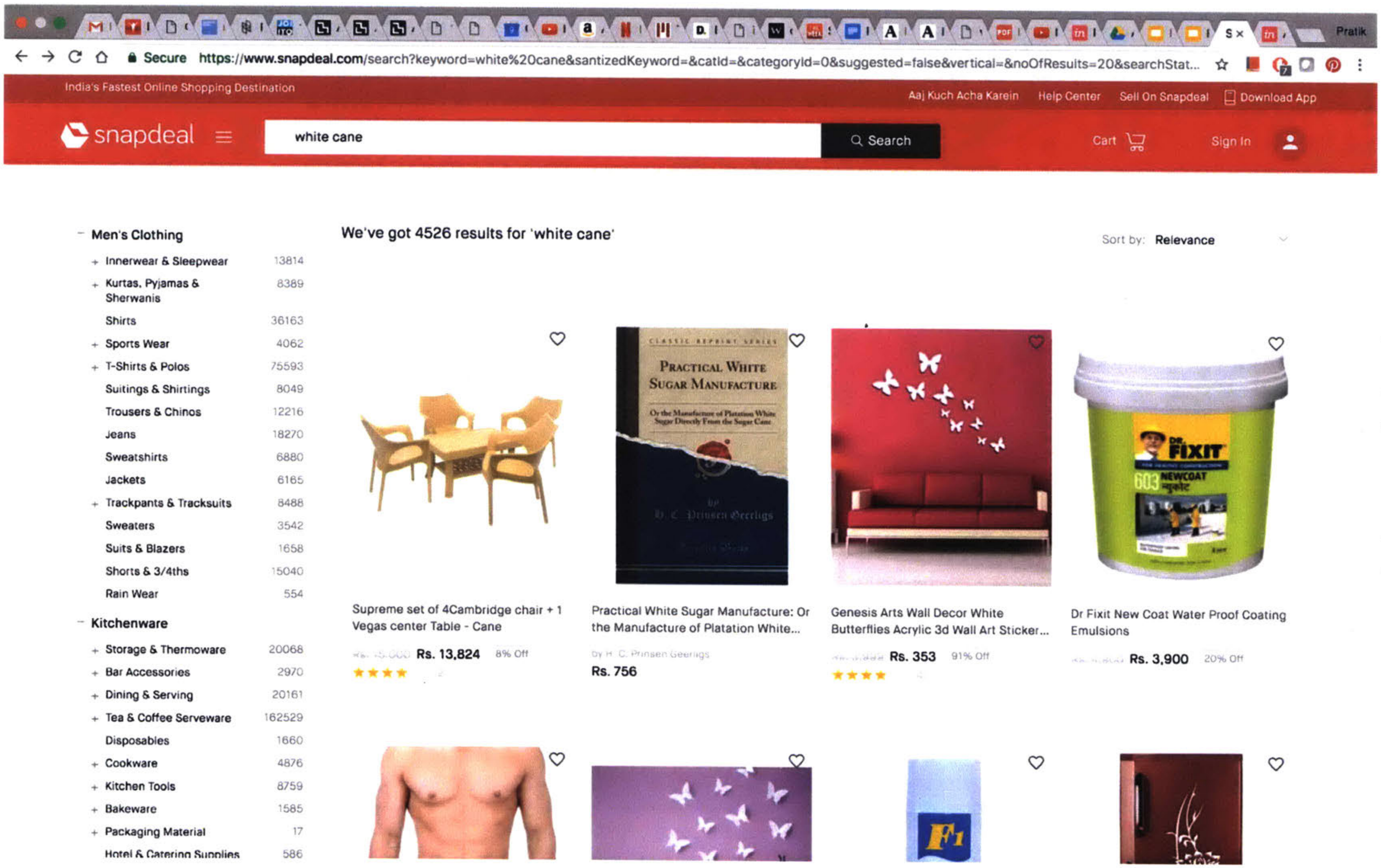
Appendix

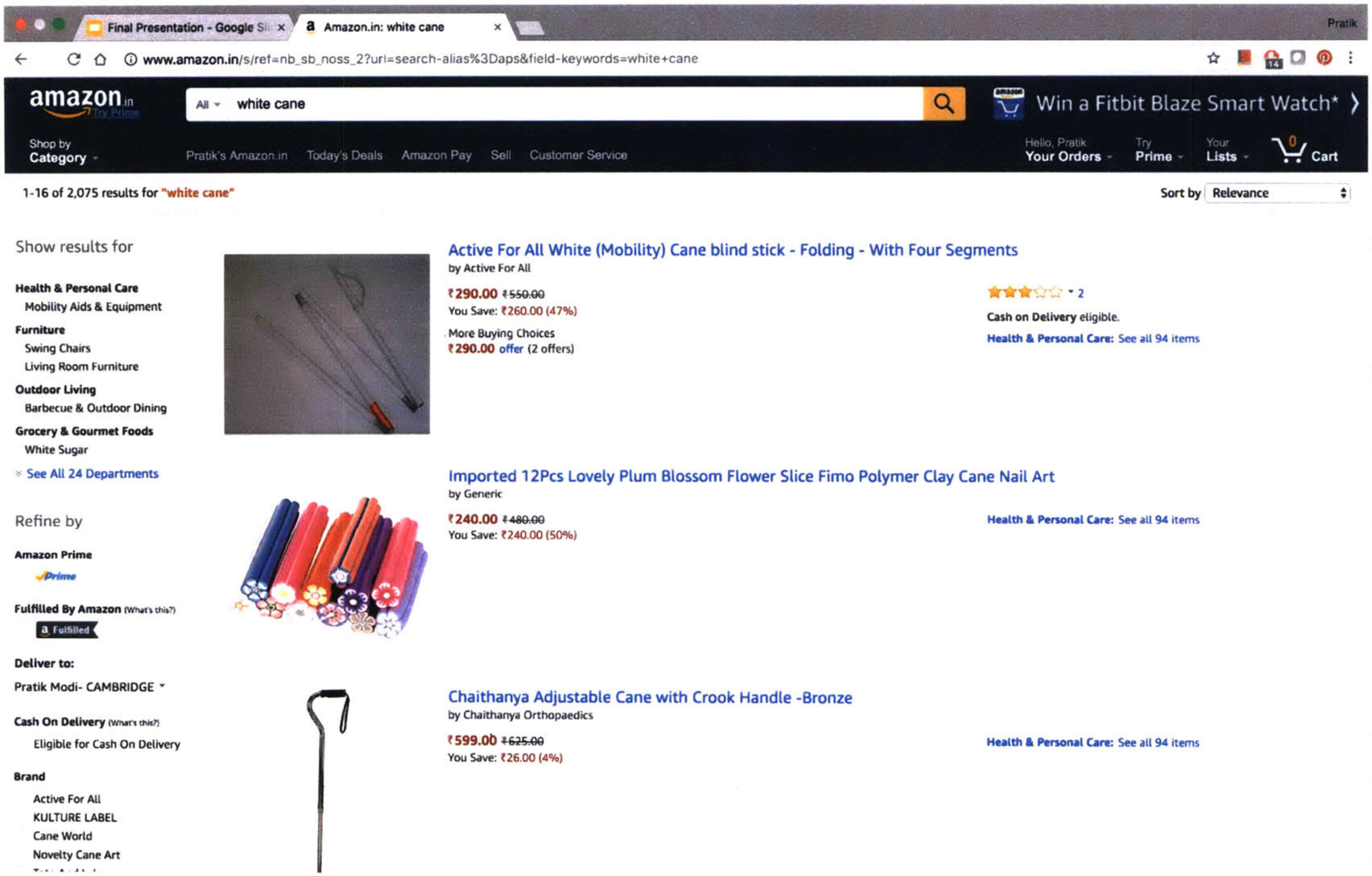
Screenshots of websites of popular e-commerce platforms, an assistive technology distribution business and an NGO:



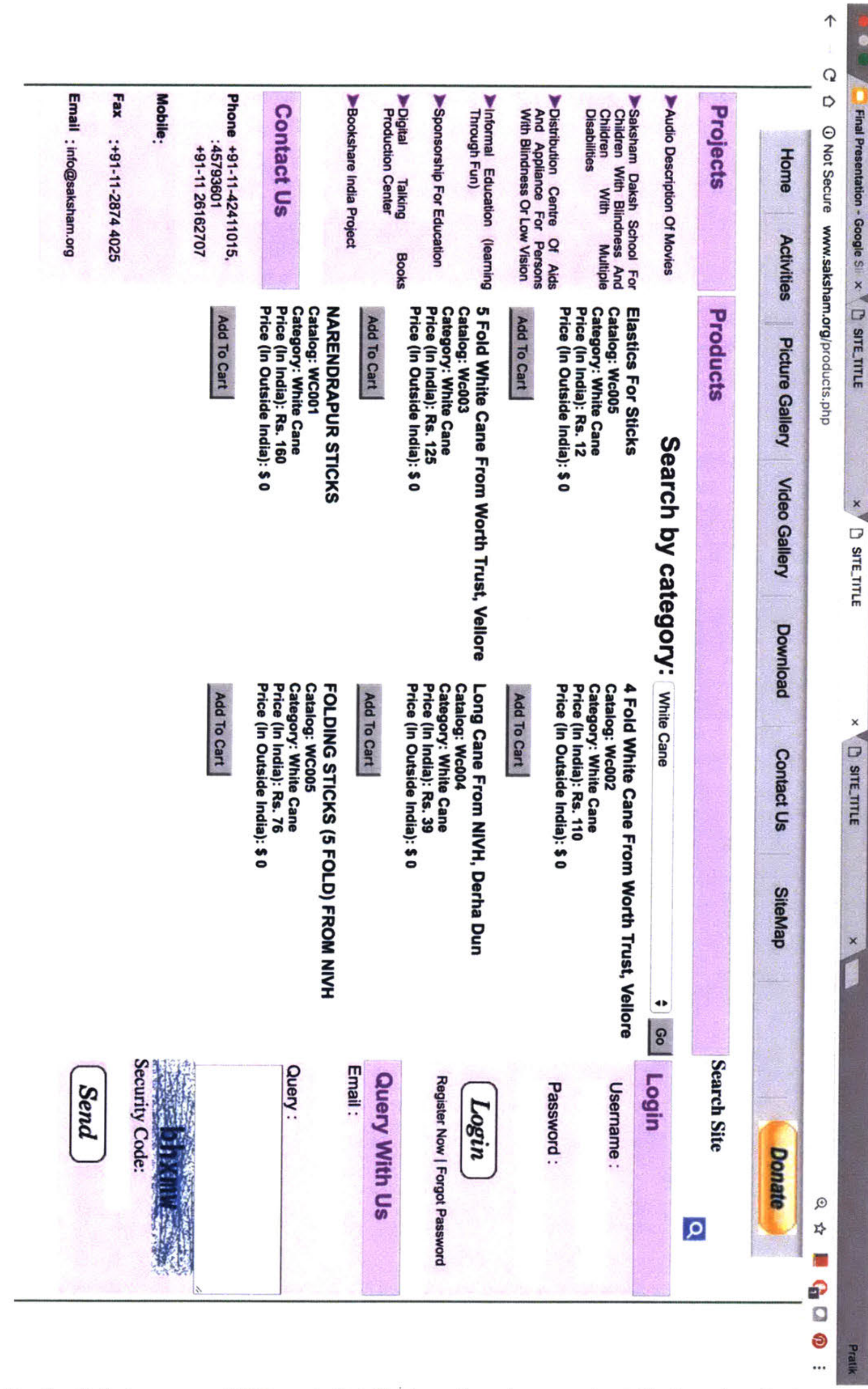
Flipkart.com results for white cane



Snapdeal.com results for white cane



Amazon.in results showing one available product at four times the price of a white cane from an NGO



Website for Saksham, an NGO and distributor showing product listings but it does not offer online payments or any more product information than shown above.

Final Presentation - Google Sl × | Plextalk PTP1 Daisy Recorder × | Pratik

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World's first Pocket Size DAISY Reader & Recorder that **converts Text files, Word Docs** and even **human voice recordings into DAISY format** directly with it's **in-built conversion facility** and also enables Downloading of **Podcasts**, Listening to the **Internet Radio,** Downloading of **E-books** from websites like Bookshare, Gutenburg, Audible through **Wireless LAN** in your home, office or institution!

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- **WiFi Enabled**

In-Built DAISY Converter: For Text, Word documents and Voice Recordings.
DAISY Editor: Using heading & section markers in record / playback mode.
Creation of Indian Language DAISY Books: Record books in any language and directly convert them into DAISY format.
Direct USB Pen Drive & External CD Drive Connectivity
Easy Navigation: Navigate between chapters, pages, paragraphs, sentences and time intervals. Alter the speed of reading or listen to the file once or repeatedly.
Professional Voice Recorder: Records professionally in 6 levels of sound quality. Has an automatic record level control with self voicing record meter. ***An ideal feature for blind stenographers, medical transcriptionists, musicians, teachers, professionals, singers, etc.***
Records up to 200 voice Memos in MP3 format
Direct Converter to MP3 Format: Records from audio cassettes, radio, DVDs etc. either directly through its high quality internal microphone or Line In mode. ***Ideal for converting existing talking books in audio cassettes especially those in Indian languages to DAISY format***
E-Text Reader: Reads DAISY text, Word DOC and DOCX, plain text or html with its in-built text-to-speech.
Bookmarks: Supports 10,000 Numbered bookmarks, 30 min. of Voice Bookmarks & 1000 resume bookmarks.
Wireless LAN: Connects to a wireless LAN directly and allows sharing of books or files with other computers, Access Internet Radio Websites & Download Podcasts automatically.
Internet Radio Streaming: You can listen to web radio from websites giving access to all international talk shows, music broadcasts worldwide.
Podcast Receiver: Download latest Podcasts with direct updating feature i.e. audio files from various web sites such as music providers, news networks, or talk radio, and keep updated to the latest technology and world news.

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Home Page

The website of Karishma enterprises, the largest commercial assistive technology distributor does not sell online, does not list prices and is not accessible