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Sketching with Tangibility

An intuitive approach to design products based on *flexibility*

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TU Delft

Master Graduation Thesis

MSc Integrated Product Design
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Preface

The genesis of this project is anchored in curiosity, an inclination towards creative exploration coupled with a keen interest in the mechanics of learning. This project is the final frontier in my journey of becoming a Master in Design Engineering at the Delft University of Technology.

I've always been intrigued by creative engineering. Engineering that involves aspects of biomimicry, robotics, origami. The subject topic for this project is mainly compliant mechanisms. This is in direct corelation with the aforementioned interests.

In my design journey I've had a chance to follow and practice the design process very closely. During the early prototyping phase of any design project there is a certain struggle in achieving clarity. This project seeks to explore compliant mechanisms and state it's relevance to designers in the early phases of prototyping.

I had to learn about compliant mechanisms ,understand the mechanics behind learning to introduce this new subject to fellow designers and professional designers.

During the course of this project, I've had an opportunity to have a direct impact on 50 design professionals through my workshop which is the final result of this project.

The experience I've gained through this project has empowered me in various ways. I have understood my strengths and have been able to solidify my foundations as a designer and a learner.

This journey has been challenging and fruitful at the same time. I have learned a great deal about myself through the creative challenges encountered in this project.

Through out the course of these 5 months, a great number of people have supported me and I have the deepest gratitude for all of them.

Starting off, my supervisory team. Erik and Stefan, you've led me through a huge milestone, this wouldn't have been possible without your clamness and patience. Erik, thank you for introducing me to your networks and giving me a headstart. Stefan, thank you for understanding me and for all the conversations about learning and the human condition. Thank you both for your encouragement and trust.

Papa and mummy, thank you for affording me this opportunity to explore and learn in a new land very far away from you. Ujin uncle for being a constant source of support, Ammachi(grandmother) for all the prayers.

I've had the pleasure of having these lovely humans who have been a constant source of fun and support. Thank you Aman, Tim, Girish, Shreyas, Priyanka and Shreya for being in my corner and for checking in on me every now and then.

Linda, Ton, and Elizabeth for all the love and care.

I'm truly lucky to have all of you in my life.

Summary

The principles of compliant mechanisms have been available to engineering students, students of mechanical engineering. Designers or design students had very little understanding of the principles behind making compliant things(Interviews).

Through the course of this project, the relevance of compliant products to designers have been outlined. The basic general principles have been outlined and an introductory workshop experience has been curated using a worksheet as a tool to guide designers in their learning journey and in helping them design their first ever compliant thing. The concept has been validated on two occasions with two user groups, one on the university level and the other on a professional level.

With the emergence of 3D printing as a manufacturing technology for prototyping needs of a designer, the FDM 3D printing technology is used in attaining the results of the workshop.

To direct the project, values of two stakeholders were considered. First, the IDE Academy, TUDelft. Second a mock business entity, Borderless Quadrant. Through these values, mechanics of the workshop such as experiential learning, conversational learning have been shaped.

The methodological approach of the project is based on the double diamond approach and has explore, define, develop and deliver phases.

During the exploration phase of the project, literature research coupled with interviews with subject matter experts was conducted. The challenges faced by product developers while designing compliant products were outlined. The current delivery of an IDE academy workshop was observed and points for improvement were noted down.

The literature research aided in formulating the basics of designing with flexibility of products.

Going into the "define" phase of the project a vision was formulated i.e **"The vision is to encourage play and exploration in the learning journey to get to simple, functional, tangible outcomes"** .

Based on this vision, a co-creation workshop was set up with a small group of designers. The learnings from this were translated as guidelines for designers. The next step was to validate these guidelines through a workshop for design students that was organised by the IDE academy. For this workshop the complexity was to deal with the higher number of participants and time. In providing the participants a consistent learning experience, worksheets based on the guidelines were made. The workshop was successful in introducing this new concept to designers, in contextualizing the relevance of designing with flexibility for them, and helped them in autonomously achieving results on the topic. The next step was to validate it with professional designers and so the workshop was conducted in a design studio. After the workshop inputs were welcomed in making it more valuable to designers in actually being able to take this skill and apply it to their design practice.

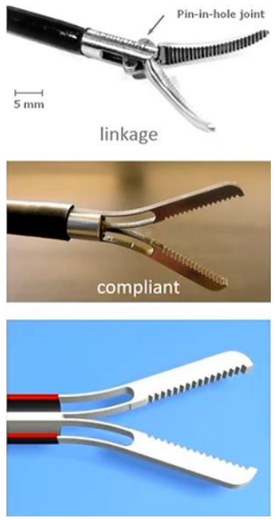
Lastly, future directions are discussed and the possibility of a business is discussed.

Contents

1. Introduction

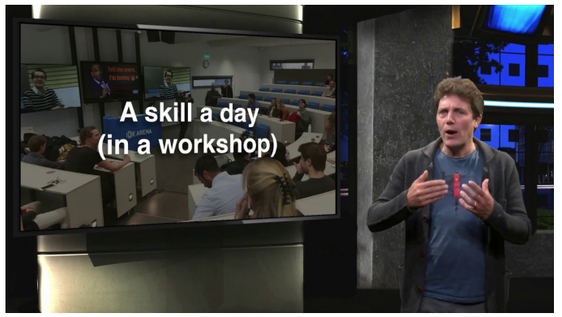
This chapter introduces the start of this self initiated graduation project. It introduces the initial problem statement and scope of the assignment. Following, the approach of the assignment is outlined.

1.1 Introduction



Compliant Surgical Equipment

Compliant Element in a chair.JPG



A day in the IDE Academy

Illustrating the context of product designers

Compliant Mechanisms have been around for sometime now, the knowledge of which exists in engineering but it is only until recently that it has been actively included/ incorporated in products. A mechanism is said to be compliant when something useful is achieved by the bending of a flexible element.

Traditionally products are designed with stiff materials that are connected with hinges or sliding joints which are made of metal. This results in an increased number of parts, assembly costs rise up and product complexity increases.

The focus of designing compliance in products is in designing flexible and strong products. (Howell, L. L., Magleby, S. P., Olsen, B. M., & Wiley, J. (Eds.). (2013))

Compliant mechanisms show promise in the emerging areas of product design such as wearable devices in sports, prosthetics, robotics, everyday use products/ tools, surgical equipments, furnitures.

The pros of compliant mechanisms include part integration, lower/

no maintenance, easier replace-ability and serviceability of parts, higher fatigue tolerance, lower weight of product weight, simplified assembly, lower usage of space in a product. The cons include low level or no knowledge in early stages of design, non linear design approach.

Since these mechanisms are not rigid body based they could be integrated with apparels,they could be closer human contact. Compliant mechanisms have better control and mobility and so it could be closer to the users supporting their ergonomic needs. This is a motivation for industrial designers to incorporate compliant mechanisms early on in their product development.

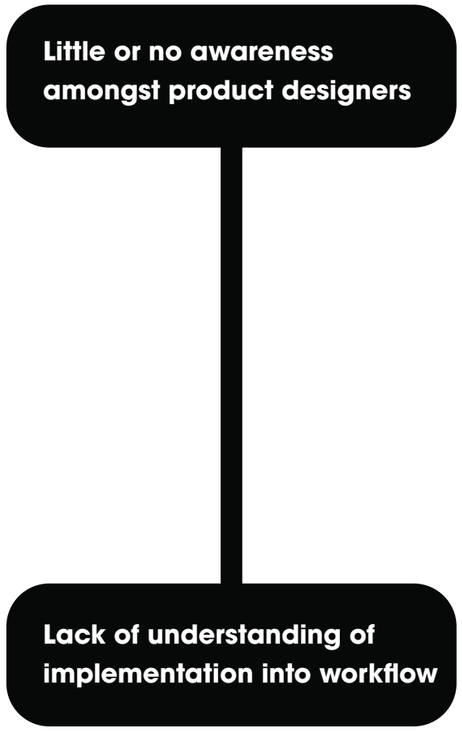
This project would encompass understanding why product designers would want to use compliant mechanisms in the product development, outlining functional requirements when compliant mechanisms could be used and when it's a better idea to go the traditional route with rigid body mechanisms. What are the core principles that a designer must know to implement the knowledge of compliant mechanisms in his/her project. What tool/s could we equip product designers with to rapidly implement compliant mechanisms in their respective projects?

The context of this project is mainly in the IDE faculty, TU Delft and practicing designers in the industry. The main stakeholders are the Department of Sustainable Design Engineering and the IDE Academy. Sustainable design Engineering department focuses on providing Industrial designers with engineering knowledge for product development and an online learning platform - The Borderless Quadrant. The interest of the department is to develop an introduction to compliant mechanisms in association with the IDE Academy which focuses on introducing designers with skills they could use in developing products. The Borderless Quadrant would be responsible to take forward the learnings from this thesis onto the internet. These stakeholders mainly cater to the students interest in acquiring knowledge in skills they are curious about or about topics that are very new to them. Complaint mechanisms fits this space very well because there aren't any resources available to students and product designers except in the realm of core mechanical engineering.

The challenge that lie in this project is to be able to help students implement knowledge of Compliant mechanisms and design a product of their own in a time constraint of 8hrs.

Thus learning and teaching would be the main pillars of this project.

1.2 Initial problem definition



The main question to be answered is "how can the knowledge of compliant mechanism aid designers and how do we simplify the understanding of compliant mechanisms so that it could be accessed and implemented by product designers during product development(from technological feasibility to demonstration i.e from TRL 1-6).

Although the benefits of compliant mechanisms are known, the knowledge about how to implement these mechanisms in early stages of product development is scarcely available to product designers.

The solution space to the defined problem could range from product demonstrations, taxonomy of these mechanisms in products, frameworks, software tools, simplified educational content without having to deal with complex calculations, learning tools for rapid skill transfer.

Through the project a clear understanding of where designers could use compliant mechanisms would be made, furthermore simplified methods to implementation would be explored and recommended.

1.3 Project Goals

Introduce Compliant Mechanisms to Designers and design students

Establish relevance of compliant mechanisms to product designers

Outline challenges in implementing compliant mechanisms in projects or workflow

Study traditional approaches to design complaint mechanisms

Outline a methodology for designers to use it in their respective workflow

Explore learning design

Implement learning design in designing a learning experience where the skill of working with compliant mechanisms would be transferred to the student/designer

Goal of this project is to introduce compliant mechanisms to industrial designers. The approach to designing compliant mechanisms would be studied, core principles of developing compliant systems would then emerge. The next step would be to make these principles and knowledge relevant to product designers. The solution space would be a strategy/ framework illustrated through demonstrations and a recommended learning path.

Why are compliant mechanisms relevant to product designers needs to be uncovered.

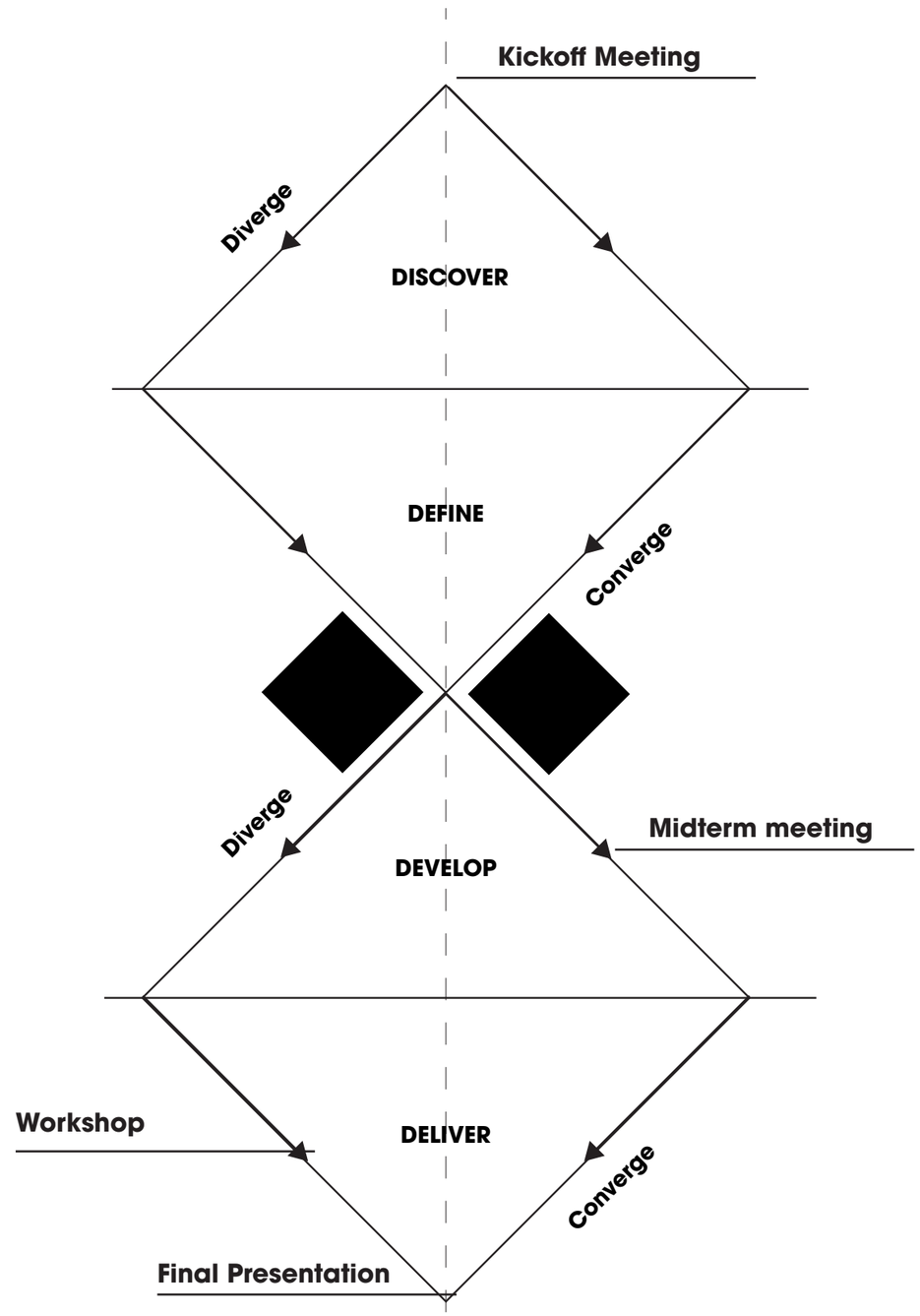
Then the challenges product designers face in developing mechanisms would need to be explored and studied.
The challenges in implementation of compliant mechanisms early on in designs should be outlined.

The traditional route including methodologies such as pseudo-rigid body models and solving non linear equations of bending to designing compliant mechanisms in engineering would be studied and core principles outlined.
It is then important to understand what methodologies would help product designers in developing mechanisms on their own.

Once a certain understanding of the knowledge area and methods of implementation are understood, principles of learning design would be studied in order to develop a learning journey for product designers to give them the tools necessary to develop a product implementing their knowledge of compliant mechanisms.

1.4 Project Approach and Overview

1.4.1 Planning and Approach



Project approach

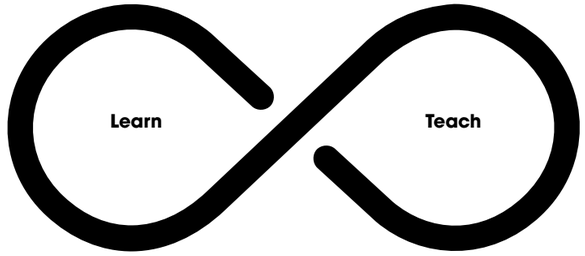
The planning aspect of this project is critical as the time constraint is set to 100 days. The project involves researching, understanding and learning domains that are very new to me and it really helps to structure the project under an umbrella structure that leads to a set of deliverables. The approach used is the double diamond(British Design Council,2019). It categorises the activities done as discover,define, develop and deliver.

The **discover** phase of this project encompasses an enquiry into the basics of compliant mechanisms, understanding it's relevance with product designers, understanding the learning experience design methodology.

The **define** phase of this project aims to frame a design vision and goal with the focus on the learner(product design student/ designers) and have a clear list of learning objectives.

Develop phase focusses on moving from the abstract to the tangible, it involves implementing strategies/ methodologies in order to develop a product through self learning and a co-creation session. In doing so a methodology would emerge which would then be translated to workshop or a cocreation session. A learning experience would be designed and outlined and iterated upon. The concept woudl then be finalised and the project would move into the deliver phase.

The **deliver** phase of the project would consist of the refining of the concept and using the Articulate 360 tool(online learning) to create an online learning journey for product designers.



Furthermore this project revolves around **learning and teaching** and so it follows a looping pattern i.e once a methodology or framework/ learning journey has been synthesised, it would be put to test in developing a product/ products in subsequent co-creation sessions. The outcomes from these sessions would then be implemented in the following iteration of the learning journey.

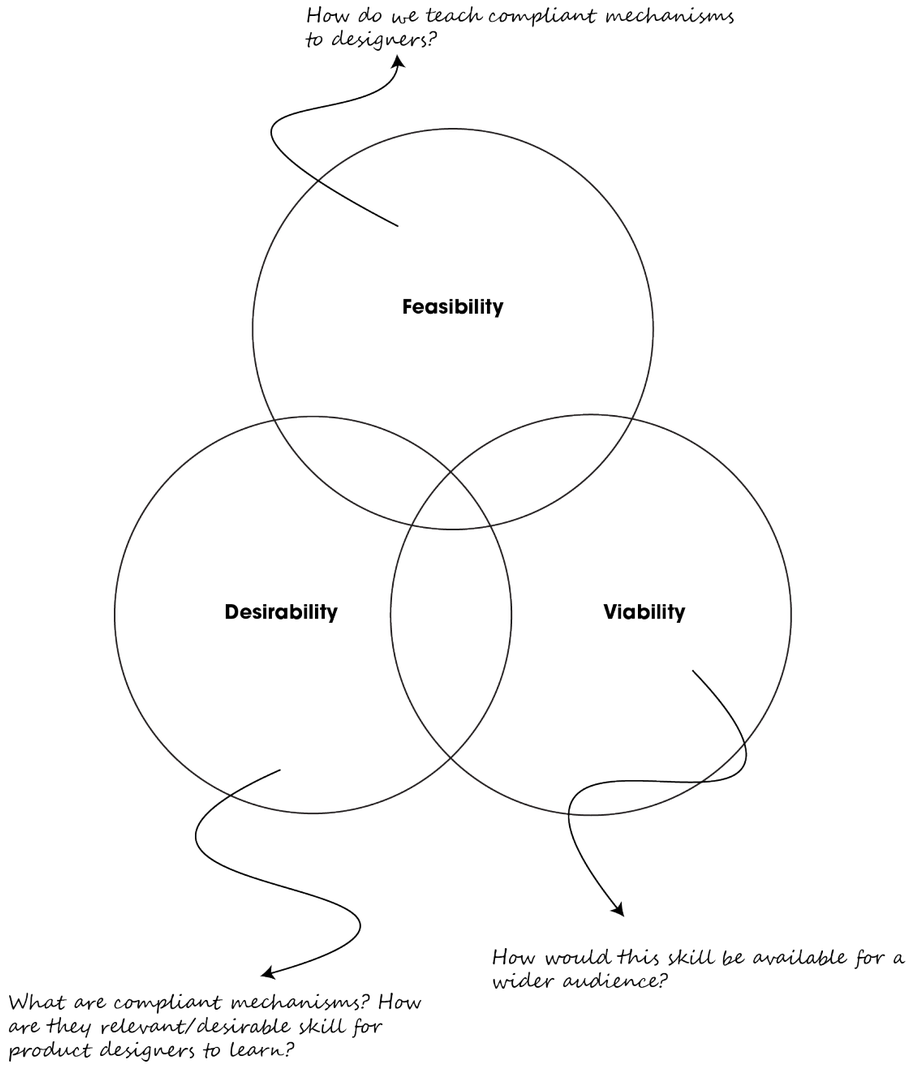
1.4.2 Research Map

During the initial stages of a project it is very easy to be carried away by the details in the existing literature and thus the human centered design approach(IDEO, 2021) is employed to guide us in asking the most relavant questions to the problems we want to solve.

Questions pertaining to the desirability, feasibility and viability are asked and a group of questions under each of these umbrellas form a pathway into the discover phase of this project.

The main research categories are **understanding compliant mechanisms ,relevance to product designers, and learning experience design.**

A more detailed version of the research map is provided in Appendix A



The **desirability** aspect in this project seeks to understand the role of compliant mechnaisms for product designers and how it could be a desirable or a relavant skill for them to learn about or acquire.

The **feasibility** part of this project concerns with answering the question of "how do we impart learning to designers about compliant mechanisms?"

Once the desirability and feasibility of the project is established, it is rather beneficial to explore the **viability** i.e "how could this knowledge and learnings be made available to a larger audience of designers(i.e outside of the university and academia)". How should it be packaged and implemented so as to cater to a wider audience.

1.5 Clients and stakeholders

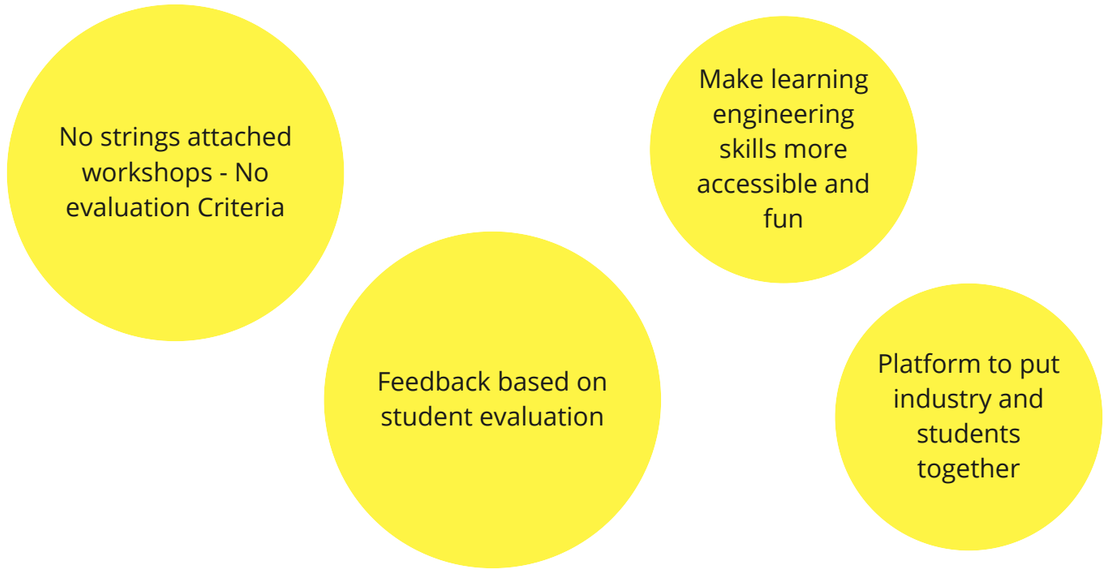
For the implementation of the results of this project and for a direct connect to the end users i.e industrial designers, two channels were identified.

The first being the **IDE academy** which conducts workshops to introduce designers to various skills from various industries(searcher. (z.d.). studiegids.tudelft.nl

The second being **the borderless quadrant**, a mock business entity which would provide access to the contents developed in this project to a wide range of audience(product designers from various backgrounds) who would want to get started on projects related to compliant mechanisms and/or simple product design.

1.5.1 IDE Academy

The main goal of the IDE academy at the TU Delft is to introduce designers to a skillset, for this project the focus would be on compliant mechanisms for product designers. There are no evaluation criteria for the course, students evaluate the workshops based on their experience of it. The manner in which the co-ordinators approach this is for the learners/students to have a good time while learning valuable skills. This is a platform where the industry meets budding talent in the university. The main values of the IDE academy thus could be outlined as novel skills presented in a fun and endearing way for designers. During the course of this project, a workshop on compliant mechanisms would be arranged, partnering up with IDE academy and the results and observations from it would be reported, discussed and implemented in the final(Deliver) phase of the project.

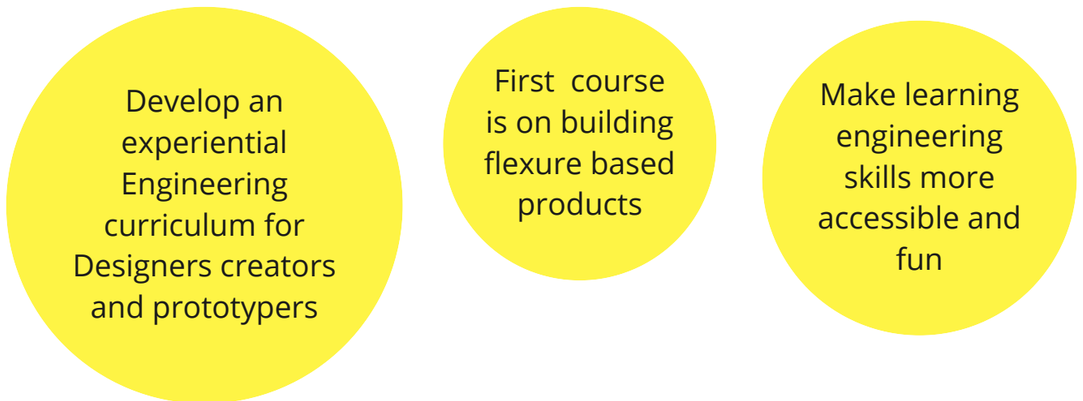


IDE Academy values

1.5.2 The Borderless Quadrant

Whilst the IDE academy focusses on providing workshops to designers in the university i.e the IDE faculty, TU Delft, The Borderless Quadrant focusses on providing educational and creative content and resources to a wider range of audience ranging from product designers, engineers, university students, hobbyists and makers. The idea behind borderless quadrant is to make engineering skills more accessible and fun. During the final phase of this project the content would be packaged and made available to the wider audience via theborderlessquadrant.com and thus the market viability of the final educational product would be assessed.

The mission of **The Borderless Quadrant** is to help it's learners get into the creative learners mindset/ growth mindset, engage it's learners by designing engaging learning experiences which makes the process of learning, engaging and simple.

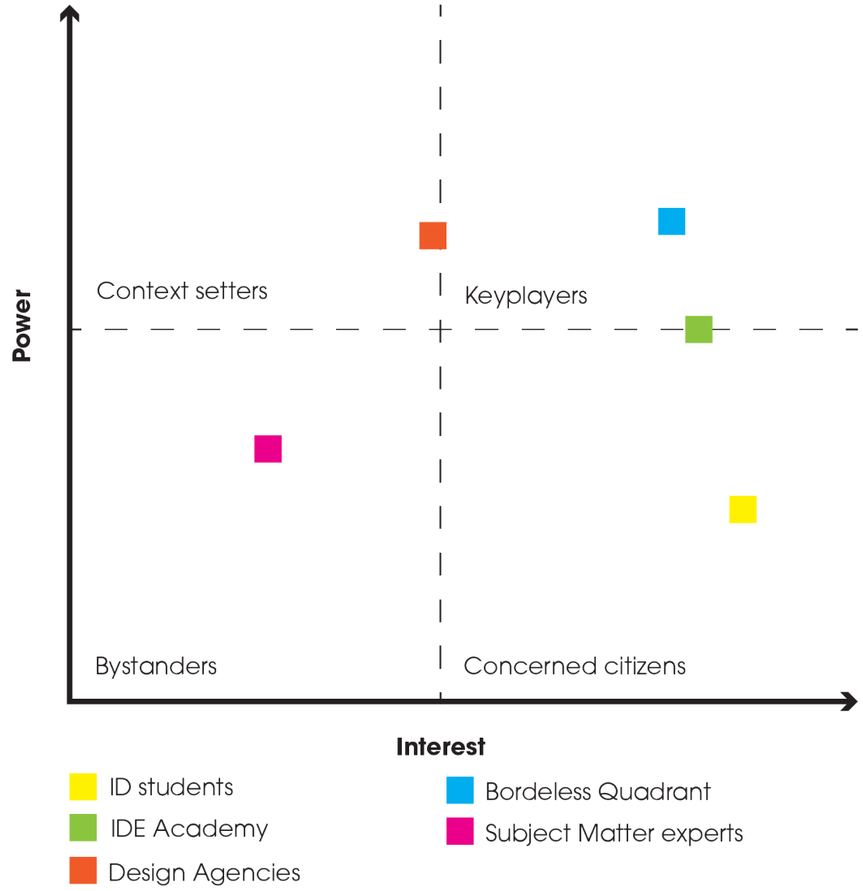


Business goals for Borderless Quadrant

1.5.3 Stakeholder mapping

Mappping out various stakeholders of this project, three main stakeholders emerged i.e the **students of industrial design, IDE academy and the borderless quadrant.** The other stakeholders with lower power or interest are subject matter experts and professsional design agencies.

The key content for this project would be developed in close collaboration with subject matter experts, product designers from the industry to develop content that is relavant to the budding industrial designer(end user). The workshop would be co-created with designers. A workshop would be organised with the help of **IDE academy** during the course of this project and the learning from the outcomes of the workshop would be packaged into an educational product that would be made available to a wider audience through **the borderless quadrant.**



Stakeholder Map

2.
Discover

This chapter focusses on exploring and understanding compliant mechanisms, the context of the learners and principles of learning design that could be employed in the develop stage of the project. Challenges to understanding and implementing compliant mechasnisms are enquired and outlined.

2.1 What are compliant Mechanisms?

2.1.1 Introduction

Traditionally when designers think of building a machine that moves to accomplish something useful, they commonly use very stiff or rigid parts that are connected by hinges(think of a door on it's hinge or wheel and axle) or sliding joints(Howell, L. L., Magleby, S. P., & Olsen, B. M. (2013)). The approach of compliant mechanisms is to emulate nature in it's core principle i.e flexibility. Nature does not have rigid parts connected with joints, instead most moving things in nature are very flexible instead of stiff. Thus we can concur that this approach to designing products is to emulate nature. The result of this approach is to realise products/ beings that have very compact complex systems eg a mosquito that has onboard navigation, control, energy harvesting and reproduction systems.

The question that arises next is, would it be possible to design better products if we looked at flexibility to design products? The answer is yes!

The applications of this approach have perculated into high tech devices such as the one piece oscillator for mechanical watches developed by Prof Nima Tolou as seen in the image on top to the right (Nieuw horlogemechanisme uit één stuk. (z.d.). TU Delft) and low tech devices such as the IKEA clip that helps us in our daily life.

While the advantages of compliant mechanisms when compared to traditional mechanisms are aplenty this approach comes with it's own challenges. The advantages and challenges of compliant mechanisms are listed below.

One piece oscillator for mechanical watches developed by Prof Nima Tolou, TUDelft

A regular IKEA clip

"If something bends to do what it's meant to do, then it is compliant"

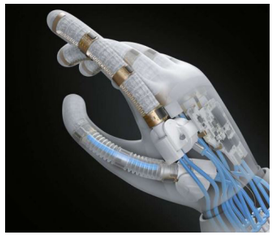
2.1.2 Moodboard of Compliant Products

Advantages	Challenges
Integration of function into fewer parts leads to lowered costs, fewer components to stock, simplified manufacturing	The integration of different functions require simultaneous design for motion and force behaviour
Potential for increased performance due to reduced wear and reduced or eliminated backlash.	Simplified linear equations are not adequate to define their motion.
Perfect for lower weight applications such as spacecrafts	Fatigue life in most of these designs must be addressed. Ideally fatigue life must exceed the life expentancy of the product that is designed.
Precise motions, more control over motion and range of motion.	Consumer perception of flexible components being clumsy or weak.
Scalability i.e once synthesised it could be put into action in small scale to large scale products.	Limited range of motion when compared to traditional mechanisms.
	Some times materials held under high stress take on a new shape associated with the stressed position.

2.1.2 Types of Compliance

In following the definition provided in the previous section, we soon discover that compliance is a generic term for deformation in a product. Deformation can occur in a variety of ways, this section covers the various types of compliance and outlines the type of compliance we're looking to discover through this project.

Compliance through soft materials. Bending in robots is very much being explored by industry heavy weights such as FESTO in R&D of bio inspired robots.



Bionic hand, FESTO

A compliant hand developed by festo is shown inthe image above(BionicSoftHand | Festo Corporate. (z.d.)).

Similarly compliance can be achieved through materials such as silicone an example of this is illustrated in the above right image(flexibility through material)

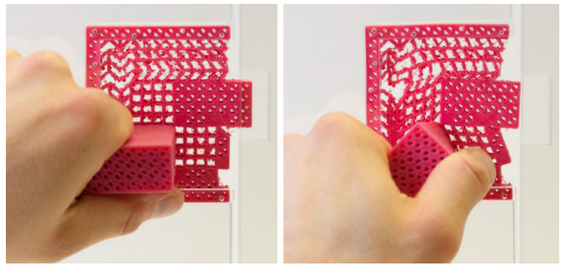
Flexibility through material

In this case the compliance is not controlled or engineered in the product, it's compliance is dependant on the material used.

Another type of compliance can be seen in the approach of meta-materials.

The Hasso Plattner institute has devised a methodology to make mechanisms based on shearing. An example of this is shown in the following image (Metamaterial Mechanisms. (z.d.). Hasso Plattner Institute). The door latch actuates based on shearing as the handle is twisted.

Finally we come to **compliance caused due to bending**. An example of a force amplifying device, developed by BYU CMR research, a plier is shown in the



(Metamaterial Mechanisms. (z.d.). Hasso Plattner Institute)

A 3D printed compliant plier, BYU

image above(Maker Resources. (z.d.). Compliant Mechanisms). This is the approach we would be studying and finding it's relavance for designers during the course of this project. It is stipulated to help with prototyping and getting to a MVP(Minimallly viable product) faster.

In designing compliant things, we're looking to facilitate deformation whilst limiting failure(Howell, L. L., Magleby, S. P., & Olsen, B. M. (2013)). Some examples of flexible and strong products are shown inthe image below of an edoscope. An endoscope is designed to be both fllexible and strong to enter and examine the human body.

Example of a flexible strong product

2.1.3 Understanding Compliance

In beginning to uderstand compliant mechanisms, we must make some shifts in our understanding of stiffness and strength. Fundamentally all the products designed based on rigid body mechanisms follow the notion of a product must be stiff to be considered strong. Stiffness and strength are two separate phenomenons.
Stiffness is resistance to deformation.
Strength is resistance to failure.

2.1.4 Principles Of compliant mechanisms

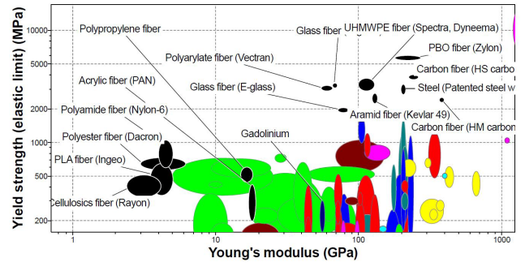
The three predominant ways to influence flexibility are the following

- Material Properties
- Geometry
- Loading and boundary conditions

Material Properties

Material stiffness varies depending on the type of material that is chosen for the design. Young's modulus (E) represents the ease of deformation of a material. A material with a higher number of young's modulus is more difficult to deform than a material that has a lower young's modulus eg the young's modulus of steel is 207GPa while that of aluminum is 72GPa. When considering deformation, polypropelene is considered since it's modulus is just 1.4GPa. That's close to 1/50th of aluminum.

When choosing for a material for compliant mechanism, it is a common approach to compare the ratios of strength to young's modulus. A higher ratio is always better.



Material chart from CES edu pack

The above image shows materials(man made fibres such as nylon, polypropelene,PLA,etc) plotted based on yield strength and young's modulus(CES Edu Pack,2019). The materials, our focus is on man made fibres (in black) that fall on the left of the graph have higher flexibility and the ones that show up on the top right corner have the highest strength.

Geometry

This is where designers could play a huge role. They tinker with shape and size all the time. Geometry plays a huge role in the flexibility and stiffness of a product. A not so flexible material could be used if the geometry allows for flexibility and the material properties of higher strength could help with the life of the product.

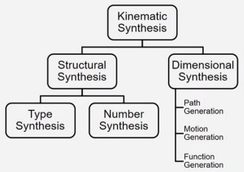
Loading and boundary conditiions

This is where the considerations on how the product is loaded i.e where the forces are acting on a product comes into play. These considerations include the constraints put on the product while loading i.e when force is being applied on it. It also includes the direction of loading. Is the product getting loaded in tension or in bending? All of these considerations makes a huge difference in the flexibility of the product.

2.1.5 Approaches to solving compliant mechanism problems

Classification of traditional approaches to compliant mechanisms, Hand book of Compliant Mechanisms

There are many ways of synthesis of compliant mechanisms while looking at it through the traditional engineering sense. That is what we'd be covering in this section. Fig XX gives an overview of methods used in the traditional sense of synthesising. These include the kinematic approach, building blocks approach and structural optimization approaches. Since this project focusses on introducing CM to product designers, we'd be delving deep into the kinematic approach, in synthesising moving parts in products. The **kinematic approach** focusses on the kinematic requirements of the product being synthesised. The kinematic approach comprises of two main methods i.e **FACT**(Freedom and constraints topologies) and the **rigid body replacement** methods. (Gallego, J. A., & Herder, J. (2009, January)) The FACT method is based on topologies i.e it maps a set of geometric entities in the freedom space into a set of geometric entities in the constraint space where the topology solutions for the design problem is found. This method makes use of computer software and is more suited for users that are initiated to compliant mechanisms, however since the focus in this project is to introduce product designers to the simplest way to synthesize CM, our efforts will be towards understanding the rigid body replacement method. The basic ideaa behind the rigid body replacement method is just as the name suggests, finding rigid bodies that



perform the intended movement/functiion and then replace it with compliant members. The classification of compliant members, two main types of compliance coud be outlined.

- Lumped compliance
- Distributed compliance

The image below gives an understanding of lumped and distributed compliance.

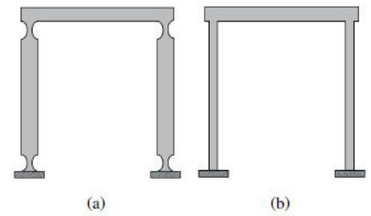


Figure 7. (a) Lumped compliance, (b) distributed compliance.

Images illustrating lumped and ditributed compliance

Design based on **flexure joints**, a flexure is a region which can undergo large deflections relative to the stiffer adjacent region of the same element.

To keep things simple, we'll focus on two types of joints i.e revolute and prismatic joints. Image on (pg 24) shows flexure elements, revolute joints and prismatic joints.

Revolute joints are joints that are used to rotate around a certain axis.

Prismatic joints are joints that allow for sliding motion in the linkages.

These approaches are used to synthesize the structure for the kinematic syntheis.

Once the structure is synthesized, the dimensions of the configuration must be synthesized.

The next approach that could be beneficial for product designers is that of the building blocks approach. In the building block approach, the primary element that is considered is the PCV(principal compliance vector) the PCV is used as the primary element in building two building blocks i.e the dyad(CDB) and the 4 bar mechanism building block (C4B). Example of a mechanism constructed via the C4B and CDB is shown in the image below. The arrows indicate the directions of the input and output force.

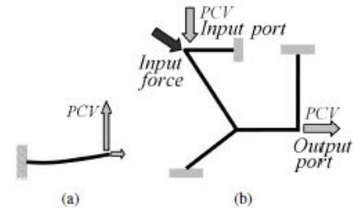


Figure 18. Principal compliance vector. (a) PVC of a Cantilever beam, (b) PVC of a compliant mechanism at the input and output port.

Principle compliance vector

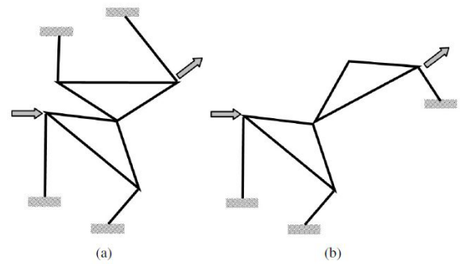
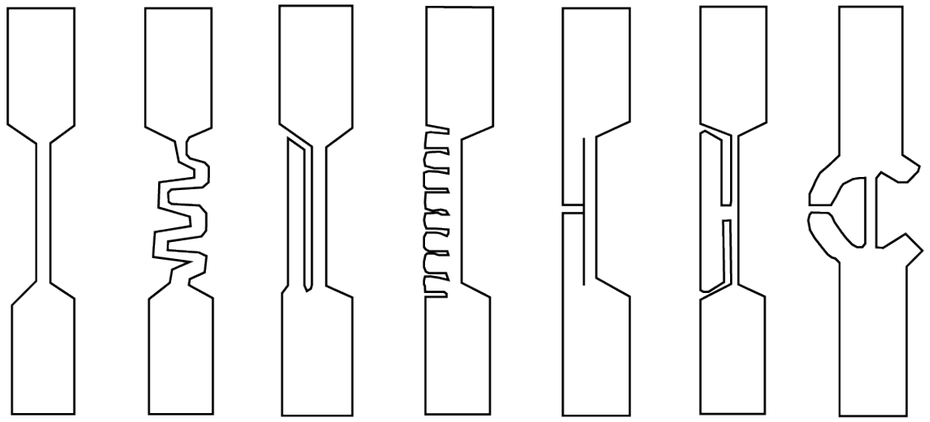


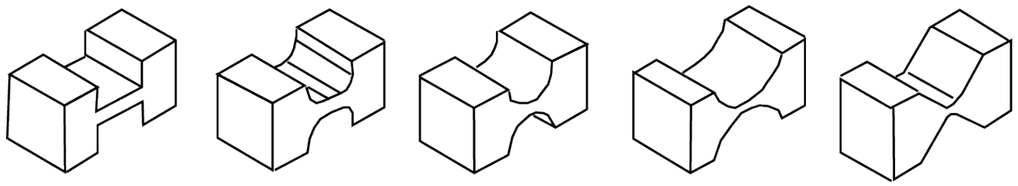
Figure 17. Building blocks concatenation, reproduced from [31]. (a) Combination of two C4B, (b) combination of C4B and CDB.

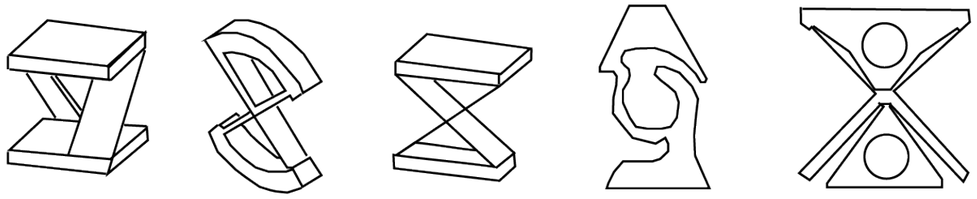
The building blocks approach.

Flexure Elements

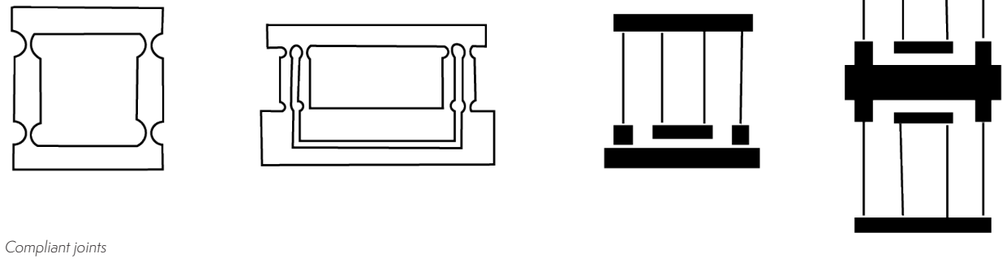


Revolute joints





Prismatic joints



Compliant joints

2.2 Challenges faced by product designers who have attempted at designing compliant mechanisms in products

Exploring the challenges faced by product developers and engineers in developing compliant products (Patty interview, Appendix B), we understand that

1) Access to quick knowledge of compliant mechanisms is limited (either full courses or superficial youtube videos)

2) In a project there is very limited time to learn new concepts and so designs existing in the literature is explored.

3) Approximating dynamic forces are a challenge and prototypes have to be conceptualised and tested.

Furthermore on discussing what could be the possible solutions to their challenges the following was listed down

1) A methodology or framework/ guideline could be of tremendous help to get to a proof of concept.

2) A basic library of compliant elements, mechanisms to refer to or download from.

3) Show relationships between parameters affecting the flexural elements.

4) A structured approach to prototyping could save a lot of time.

Problem space :

No quick access to structured knowledge of compliant mechanisms

Limited time in a project

Approximating forces is always a challenge, the system must always be prototyped

Lorem ipsum

Lorem ipsum

Solution Space

Methodology/framework

A basic library of compliant mechanisms and elements

Show relationships between basic parameters

Structured approach to prototyping - Guidelines.

2.3 How does the knowledge of compliant mechanism help product designers?

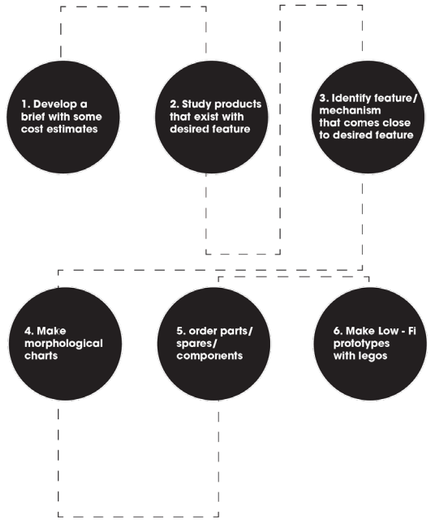
2.3.1 Relevance of Compliant mechanisms in the Product Development Industry

In order to understand what industry professionals thought of the approach of compliant mechanisms as a tool in their arsenel of various tools such as sketching, basic electronics etc interviews were conducted(Appendix B) and problems briefs were onboarded.

At first an understanding of the product development process in a high paced environment such as a design agency was outlined in the image on the top right corner(process of product development at a design agency).

From that discussion it was apparent that compliant mechanisms approach is very new to product designers and that they did not have any source of inspiration to derive from to use in their projects. In order for them to feel comfortable with this approach, demonstrators were requested much like the ones manufacturing companies provide them with as seen in the images (below)

On enquiring further about how product designers could benefit out of this appproach, we understand that it could help with the following i.e getting **tangible results at the conceptual stage of designing through desktop manufacturing methods that means a faster MVP(minimally viable product)**, better form function integration especially in products that touch the human body/skin(Patty interview,Appendix B), this approach could result in simpler products(part

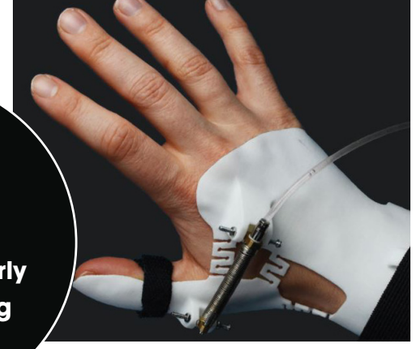


Process of product development at a design agency

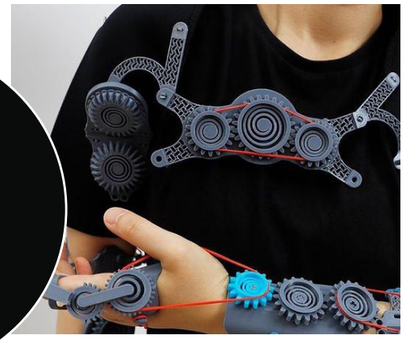
Demonstrators from manufaturing companies.

integration), more freedom for the designers not to depend on sourcing different parts and scalability. We also learn that the approach of CM could help with producibility in terms of assembly and disassembly(Johan interview, Appendix B) which directly has an effect on sustainability and eco friendliness of the product. This approach helps product designers to design products based on principles found in nature i.e deformation

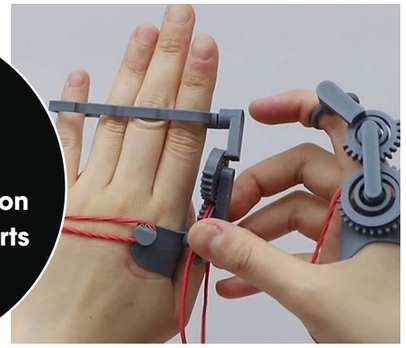
Better Form function integration in early stage prototyping



Result in simpler products



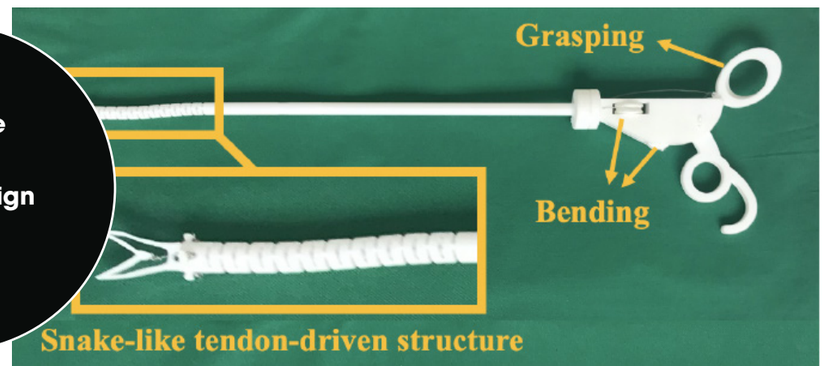
More freedom for designers without being dependant on sourcing fitting parts



Easier assembly/ disassembly which has direct corelations with sustainability

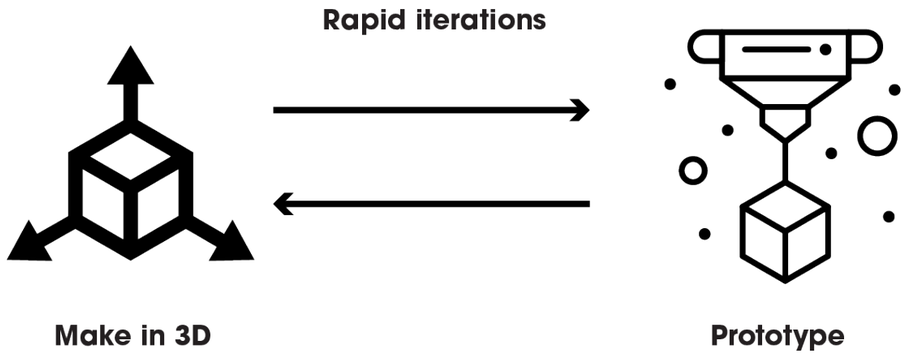
Scalability, same product of different sizes could be easily produced

Helps realise bioinspired product design



2.3.2 Understanding approaches of designers in solving compliant mechanism problems - 2 Case studies

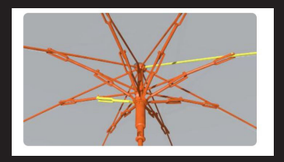
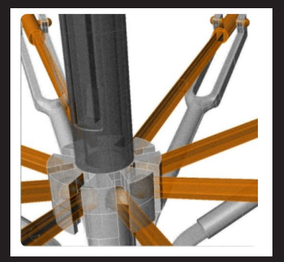
It is of interest to see if product designers have used this approach of compliant mechanisms and if so why. Two cases were identified and studied the first being that of **Crayella** an umbrella that satisfies the cradle to cradle approach in achieving circularity, designed by Erin Macdonald (MacDonald, E. (z.d.). Crayella).
The second being the case of Herman and Miller **Setu chair** designed by a German product design studio, Studio 7.5. The brief gven to them was that of acheiving sustainability.
The result of this exploration was the Setu chair that is 93% recyclable(Mings, J. (2009). This chair could bend and move with every small movement of the user.
The material used for the compliant parts of both these products is polypropelene. Both these designs have sustainability as a common goal.

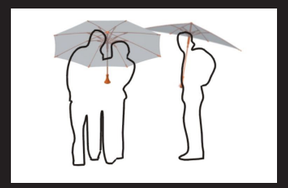


Crayella, is designed to improve repairability. It's USP is that no tools are required for it's assembly. Flexures are used instead of springs thus lowering the part count in the Crayella.

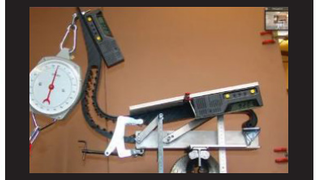
Apart from the flexures as springs, crayella can be snapped in without the need for sewing. This saves cost, and time in producing.

The approach in designing crayella as seen in the figures is 3D modeling and then prototyping, iterating on to get to a fully functional prototype.

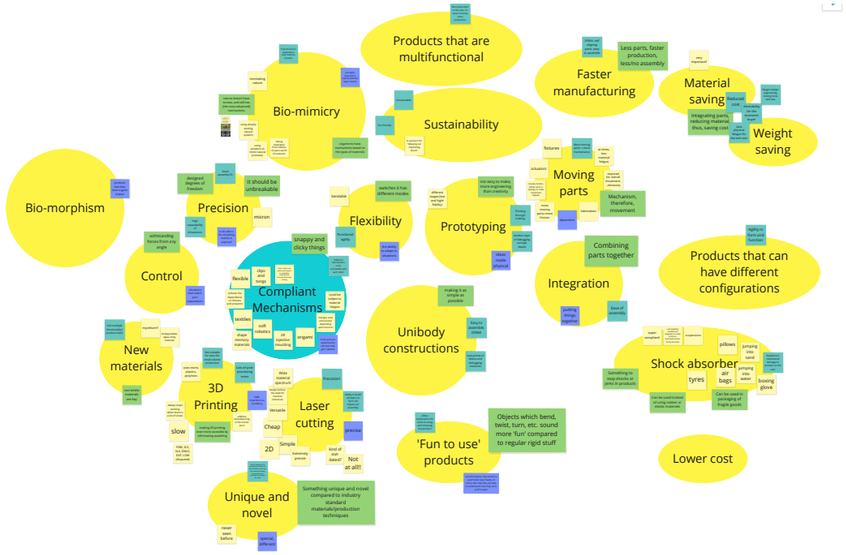


The Setu chair, was designed to improve comfort for the user and at the same time improve repairabilitty. The feature that allows for both of these requirements to be realised is the kinematic spine which is the compliant part of the design. It is inspired by the spiral of the nautilus shell shape, the process of prototyping and testing led the design team to make 30 prototypes. In enquiring more about the process we understand that everytime a 3D sketch was made, a scaled version of the model was either hand made or 3D millled. Going back and forth from the geometry seen on screen and modifying the physical model is the best way to realise and learn from the previous iteration.


2.3.3 Needs and Aspirations of Product designers

In trying to understand how the knowledge of compliant mechanisms would help product designers, it is important to understand what industrial designers value and aspire towards. To understand this, a word association activity was set up followed by a questionnaire. 10 designers from various backgrounds participated in the word association activity whilst 5 of them answered the questionnaire(Appendix E). The word association was set out to understand what industrial designers associated with complaint mechanisms, the questtionaire gave more of an understanding of what they really thought of the approach.



Word association activity with designers

The recurring themes in the questionnaire and the word association are **simplicity in products, prototyping, integrations/unibody constructions**.

Mapping inputs from product design companies.

Earlier in the research phase product design agencies had been asked as to what they'd like to implement the compliant tech approach into(Appendix B). The cases were grouped into the following categories i.e Latches/ locking mechanisms, load transfer(force amplification), **part integration and reducing complexity in products.**

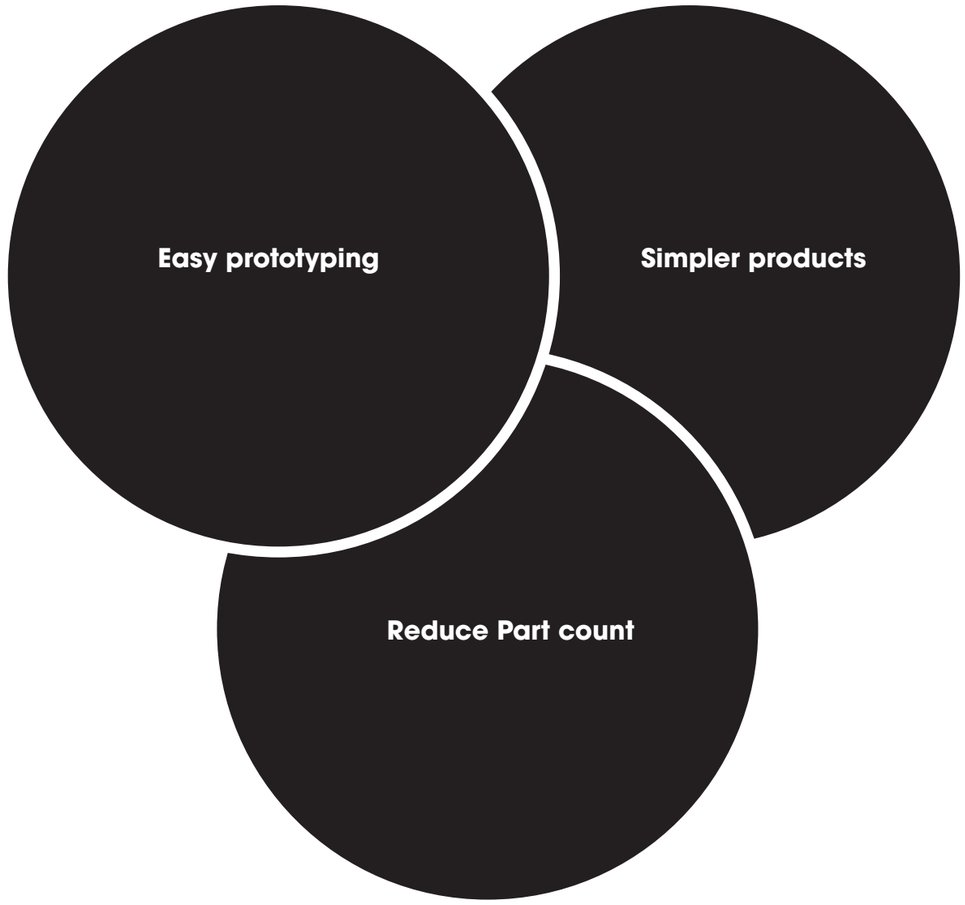
The overlap in interests are in simplifying products and part integration.

From this we establish that the aspirations of industrial design learners are three fold.

1) To be able to prototype easily.

2) To be able to make products simpler.

3) To reduce part count in products for easier producibility.



2.4 How do we impart learning to product designers?

The task of introducing certain skillsets to product designers isn't a new endevour. Educators such as Camile Mousette and Paul Jackson have done it before in the fields of haptics and origami respectively.

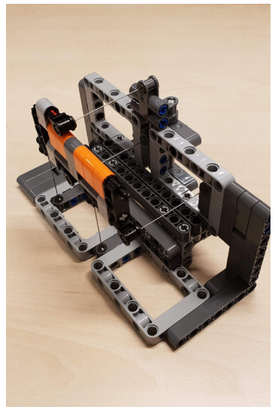
In his PhD thesis titled simple haptics, Camile explores the field of haptics and introduces it to designers. He proposes the **make to learn, learn to make** approach to develop and explore simple haptics and it's possibilities with designers. He organises workshops and learns the potential from them as he introduces his own explorations to people participating in the workshops(Moussette, C. (2012)).

His initially set out to outline tools for designers to improve accessability of haptics. As he progressed, he realised that the best way to understand and discover is by making simple devices himself with the principles of haptics.

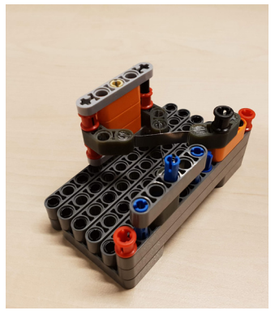
Learning by doing example, Camille Mousette

Learning by doing example, Camille Mousette

In a similar approach, Paul Jackson, in his seminal work, folding techniques for designers instructs to play with paper, the first prototypes. He aims to make folding which is normally considered uninspiring a common place in design practice. He invites the learner to play with the concepts discussed in his book. The book although invites the learner to play with his/her designs is crafted in a more structured approach, giving clear guidelines to the designer in achieving the basics. The basics of folding are listed out in detail so the learner is not lost in his/her initial foray into the craft.



Example of delivering an understanding of compliant mechanisms through legos, Interviews - Appendix B



Example of delivering an understanding of compliant mechanisms through legos, Interviews - Appendix B

On enquiring about how complaint mechanisms are taught to engineers researcher and educator(Appendix B), Renier pointed out to hands on approach as the most effective way of educating as it has an intuitive appeal. The feedback is instant and the person interacting with the hands on device learns a thing or two about the functionality of the device and grasps the principles used via his/her own observation, that is more powerful than any educator or facilitator trying to explain.

"I always took a very practical and hands on approach. You cannot really learn an intuitive sense for compliant mechanism from books and computer simulations/ calculations. You have to actually feel the devices, you have to interact with them, play with them in order to truly understand their behavior. Then it becomes possible to internally visualize how compliant mechanism will behave and this enable of course a large amount of creativity"

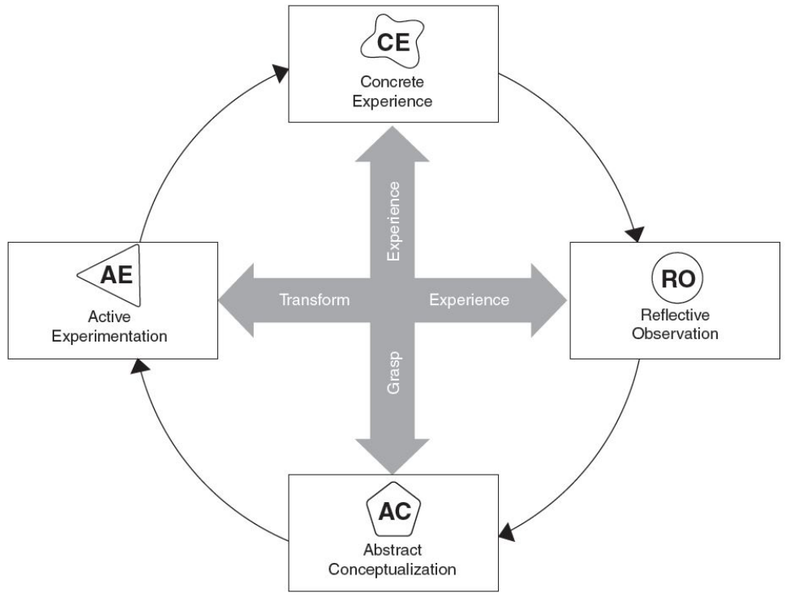
"Productive failure is a good approach. The thing is failure is difficullt and people don't want to go through it. Once a person comes out of a failure, he has learnt a lot"

"If you have 30 students, you'd want to give them assignments having some variations but based on the same theme. Put them in groups of 4 or 5 and then in the end you have variety in the results achieved during the day"

2.3.1 Expriential Learning - Kolbe's learning cycle

Experiential Learning : "Learning in which the learner is directly in touch with the realities being studied. It is contrasted with the learner who only reads about, hears about, talks about, or writes about these realities but never comes into contact with them as part of the learning process."(Keeton and Tate, 1978)

The discussion and insights from the previous section directly brings us to experiential learning, the approach to imparting learning through direct sense experience or in context action as the primary source of learning, often down playing a role for thinking, analysis, and academic knowledge(Kolb, D. A. (2014)).



The experiential learning cycle, Kolb,DA,2014)

The experiential learning cycle is a dynamic view on learning outlined by Kolb as a resolution of dual dialectics of action/reflection and experience/abstraction. The cycle starts with e learner having a concrete experience, which is followed by reflective observation. Using the experience and the observations, it's time for the learner to conceptualise it. Once it experience is conceptualised, active experimentation needs to be done which results in another concrete experience. This is a recursive process and learning arises from the resolution of the creative tension that exists between these states in the cycle.

2.3.2 The learning journey

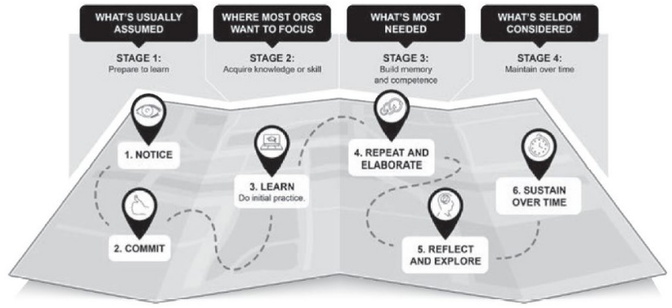
With the goal of imparting a valuable learning experience we often think of workshops or lectures as one off events as opposed to a part of the learner's journey (Boller, S., & Fletcher, L. (2020)).

First of all the learner's journey must be taken into account before designing any kind of learning experience or intervention.

Boller outlines 4 stages to a learner's journey as represented in the image titled the learning journey .

The first being **prepare to learn, acquire knowledge or skill, build memory and competence** and lastly **maintain over time.**

In the first stage i.e **prepare to learn** the learning experience designer must get into the mind of the learner, what are his/her motivations? the need of the hour is to appeal to the learner to overcome a common



The learning journey, Boller, S & Fletcher, 2020

goal.
Thus the first step in the prepare to learn stage is to notice a need or an opportunity for the learner to learn. Once the opportunity has been established, a commitment from the learner is required. A commitment could be an action such as signing up for a course, purchasing a book or a course, signing up for a workshop etc. It is very important for the designer not to assume things at this stage, most frequent being "they don't need to do much". At this stage the role of the experience designer or the facilitator is to find a way to draw attention or cultivate interest in the minds of the learners. This is the time when the designer should convey or help learners understand why the content matters.

"Getting a learner to stick with a journey to the end requires careful thought and planning as well as clarity on what will make the journey a relevant one for the learner"

The stage 2 is to **acquire knowledge or skill.** The only step involved in this stage is to learn and practice. This step involves the learners to form connections to what they already know. It is very important to be able to structure the content in ways that the learners can quickly grasp what is conveyed. While it is important to show demonstrations and examples of previously worked out examples at this stage, it is equally important to let the learner get involved in practice, there must be considerable time allotted for practice.

The third stage is **building memory** and implementing it on the job. This particular stage has two steps, the first one being repeat

and elaborate.
In this step the idea is to create space for safe practice, this would ideally happen after a while the learner has taken up the course or the workshop. There must be some opportunities to recall practice what went through during the course. Thus it is important to create additional recall peripherals to the learning experience.

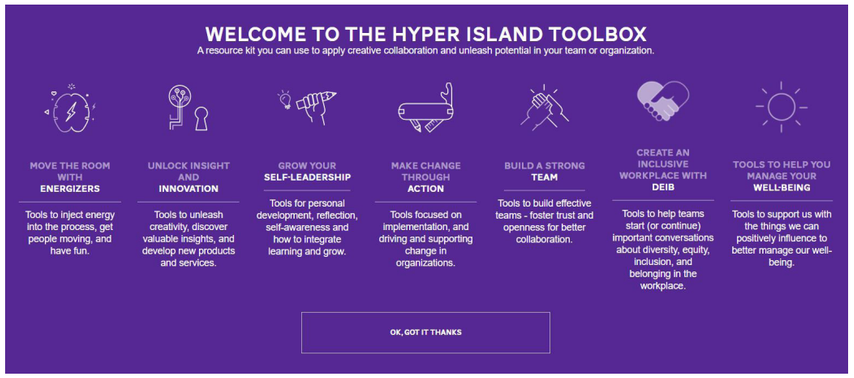
The next stage is to **maintain over time**, it is important for organisations to ensure the right kind of support and resources to the learners to help them perform newly acquired skills to satisfactory levels.

In the context of this project, **the most important stages are preparing to learn and acquiring skills**. In the following chapters, these two stages would be ideated and refined to form a concept for a learning journey.

2.3.3 Hyper Island approach

When searching the internet for methodologies for playful learning experiences, Hyper Island showed up quite a lot. it is an organisation that imparts design education in a different manner when compared to universities. The methodology to their workshops are as portrayed in the figure. They have managed to have tools for wellbeing and a methodology for inclusion in workspace which are novel ways to think about conducting workshops and developing a warm environment for the workshop to happen. (toolbox. (n.d.). Hyper Island.)

In one of the experiences shared by an alumnus, a lot of emphasis is on the learner and his/her experience, learning is fun and the most important thing is the feeling of achieving something by the end of the day.



The hyper island toolbox, Hyper Island

Learning by doing is the order of the day. As the learner puts it, it's a lot about self revelation and self discovery, seeing one's self in a different light(Wikström, A. (2019, May 19)). They focus a lot on the awareness in the learner. Gleaning from the article it is evident that proactive learning is emphasised.

Attitude of the learner to solve challenges :

"I haven't done that before but it looks interesting! I will look it up and teach myself!"

2.3.4 Observational analysis of IDE workshop - Generative Design - current scenario

In order to understand how an IDE workshop is organised, an observational study was conducted by witnessing a workshop(Appendix D).

The goal was to understand the logistics and challenges there are in introducing a new topic to designers in a very short amount of time(8hours). Through the experience a number of observations and learnings have been gathered and listed down as follows.

1) The premise of the workshop must be set up, the stage must be set for the learner to be able to pick up the skill and why he should do that.
2) The facilitator/coach must be on top of the activity and must be able to guide the learners.
3) The learners come out of the workshop with their own creation that is unique to them. This gives them a sense of achievement and a sense of learning.
4) The focus of the activities must be to convert information into tangible understanding from the very start and to be able to build on it.
5) The workshop gave them a body of work that they could show off in their portfolio.

Ideas for improvement:

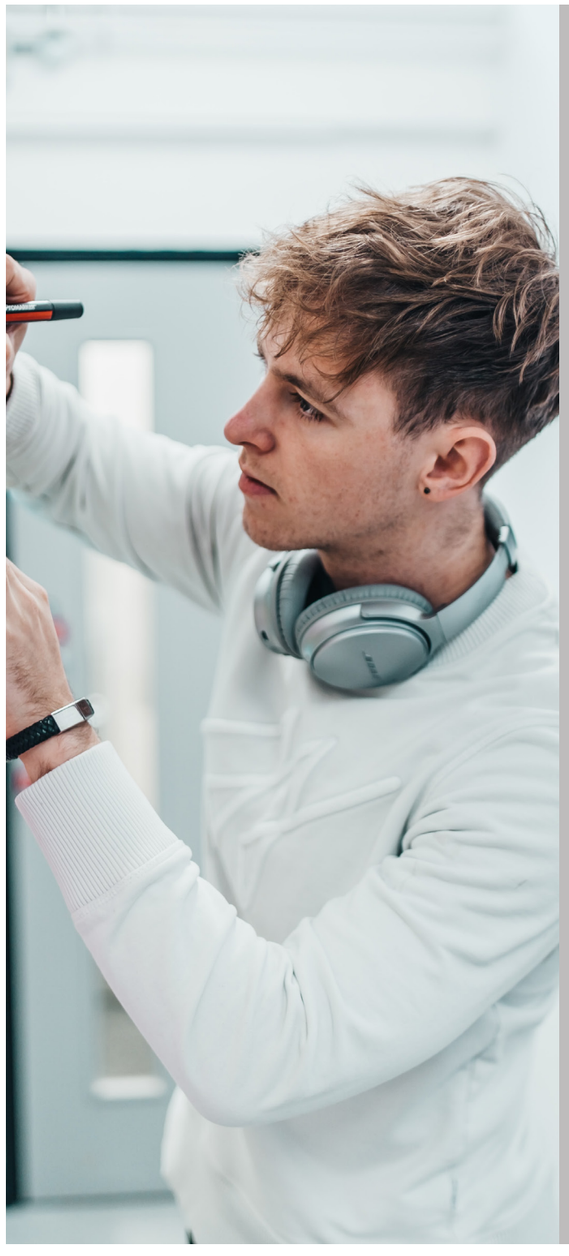
1) **Social interaction** among students could improve and it sets the stage for conversational learning to happen.
2) Since designers have an intuitive approach to solving problems a lot of them were unsure of what values to put in for forces in the software to get an acceptable result, this is an opportunity to inform the learners in a very simple manner(simplistic approach). There must be a **guide to the very first experimentation** of the concept
3) **Invoking a sense of individual contribution** to the learning experience, a voice to every person.
4) **Equal participation** from all learners must be encourageed in order for them to learn from each other.

3.
Define

This chapter focusses on outlining the goal and vision of this project. The scope of the project becomes more defined and the next steps for development are outlined. Firstly learner personas are outlined, their goals, interests and attitudes are made clear. Secondly the goals of the project are explained and envisioned learning outcomes are outlined. This helps in having a clear vision for the develop phase where the learning experience/ journey would be developed.

3.1 Personas

Learners come from varied backgrounds and at the IDE academy, it's a mix of students from various industries looking to gather an understanding of a skill in a day's time. It is impotant to personify our most important target group so that we're attuned to their needs and behaviours as we move towards designing a learning journey for them. Please note that these personas do not resemble real people.



Johan Van Nelle

Age 30
Occupation/Title Product Designer
Attitudes to learning Fast, effective, low patience, stimulated by new topics
Goals To do effective and important work in realising product concepts that are beutiful but at the same time are functional.
Interests Cycling, sketching, rendering
Frustrations Everytime I want to get into prototyping, I am faced with so many challenges! I don'have a mechanical background so I really struggle in the workshop. I hope there was an easier way to get to tangibility.

Arun John

Age 26
Occupation/Title Product Designer - Mechnaical Engineer
Attitudes to learning Curious,excited,likes discussions
Goals To llearn something new, not fully sure what he wants to do, excited with new technologies, likes to get to a minimally viable product concept very fast.
Interests Cooking, running, music,, reading
Frustrations Although I do have an understanding of mechanical engineering, the workshop environment is kind of new to me. I have pivoted my career into industrial design and I'm looking at skillling my self with the most relevant skills for this career.

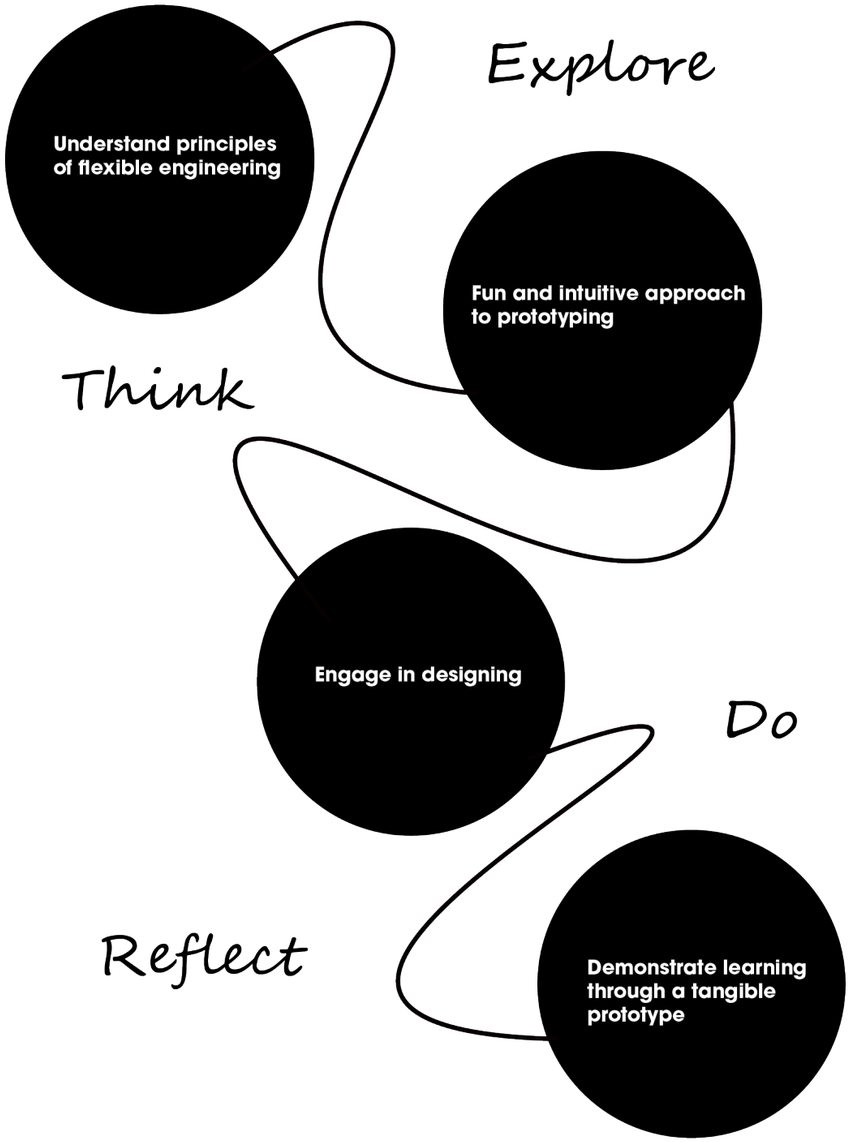
Rebecca Johnson

Age 24
Occupation/Title Interaction Designer
Attitudes to learning Curious, happy, likes getting out of her comfort zone.
Goals To understand the needs of the consumers and embody it in early stage prototypes.
Interests Photography, reading, cycling, skating
Frustrations I'm not good at developing hardware products, I'd love to know some basics of developing prototypes because I'm required to do it but I often fail at it. I want to know how to make simple effective prototypes to I can take better decisions in the design process.

3.2 What is the goal and vision of this project?

The **goal** is to develop a learning journey to help product designers skill up on principles of compliant mechanisms(flexibility based engineering) and demonstrate their understanding via a small functional product prototype.

This goal translates to explore, think, do, reflect based on the experiential learning cycle discussed in the previous section.



"The vision is to encourage play and exploration in the learning journey to get to simple, functional tangible outcomes, demonstrating rapid skill transfer"

3.3 /coping problems and challenges

The purpose of this section is to single out the problems and challenges that would be focussed on in the project, going forward.

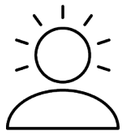
One of the first challenges is to **involve product designers(increase awareness)** in the conversation about compliant mechanisms and **it's relevance to them.** This basically revolves around educating and increasing awareness through co-creation sessions and workshops.

Once the relevance is outlined, **access** to structured knowledge is needed to implement compliant mechanisms in their design projects i.e to guide them to start creating small mechanisms/ products themselves. Thus improving their confidence in working with compliant mechanisms.

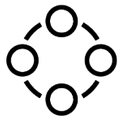
It is vey important to create and fail to gain clarity on the direction to be taken to get to a successful prototype, the ability or motivation to keep iterating comes from play and exploration, learning from previous iterations. This results in rapid skill transfer.

It is very important to finish the loop of iteration to learn from it.

The focus of the project from now on would be to provide a general framework, guidelines to finish the first design loop of making a compliant product, part or feature which resullts in a tangible prototype to learn from.



Increase awareness



Outline Relevance

Improve accessability to structured knowledge

Encourage play and exploration to design and prototype

Rapid skill transfer

Goals for the workshop

3.4 What are the envisioned learning outcomes?

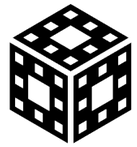
In trying to understand how learning outcomes are formulated, from Stefan's interview(Appendix B) we understand that learning goals are formulated in a broad sense so that the learner has his/her own way to navigate the learning experience. The learning outcomes envisioned for the designer are multifaceted.

Thinking in **simplicity, improving learner confidence in rapid prototyping, develop an understanding of compliant mechanisms, be able to design a tangible feature in a product with the principles learned.**

At the end of the session, participants must **know how to prototype easier, an understanding of how to make simpler products and be knowledgeable in reducing parts in products.**

Think and sketch in 2D

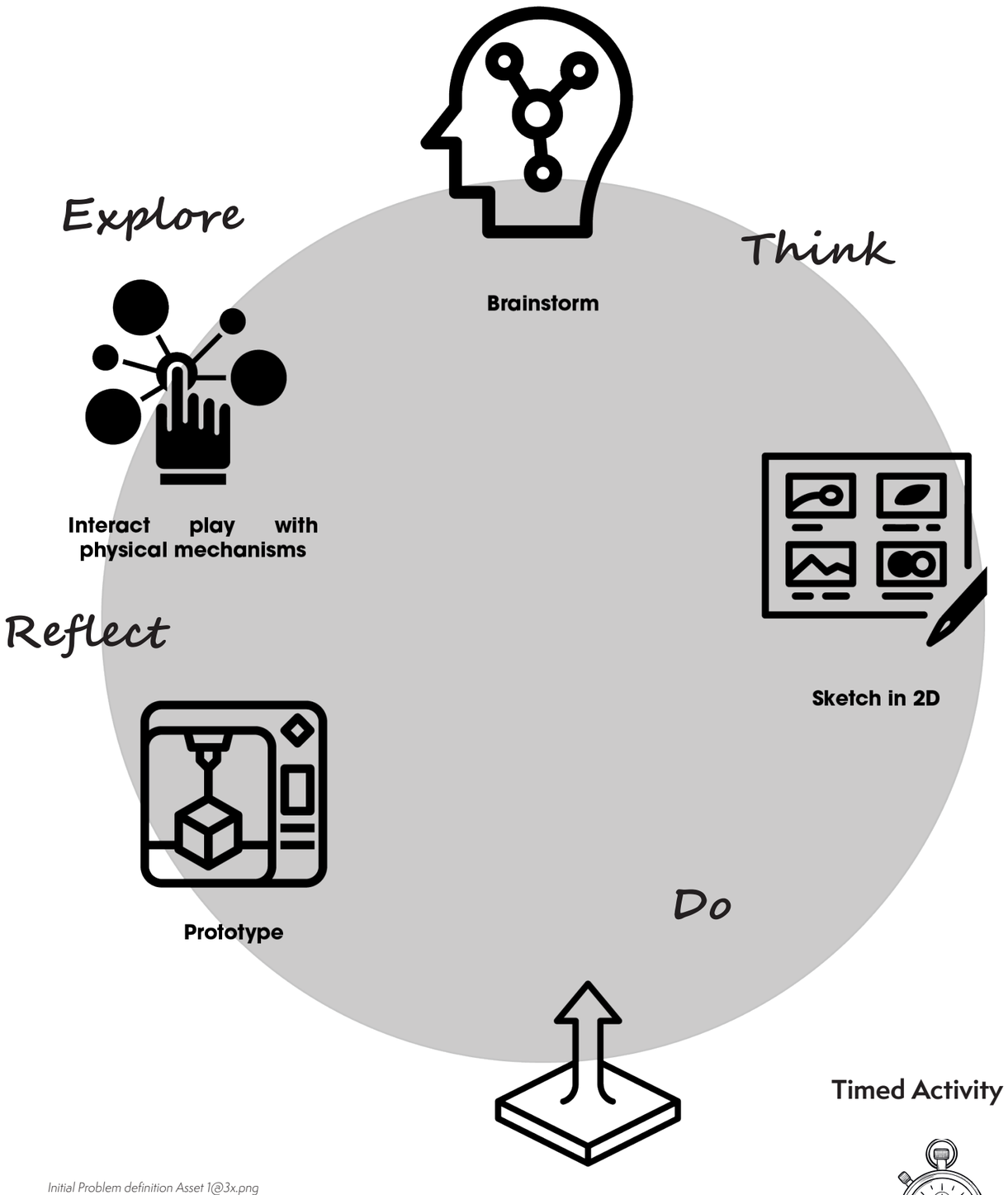
Improve confidence in finishing the first iteration



Make in 3D and reflect on outcome

Initial Problem definition Asset 15@3x.png

3.5 What does the envisioned learning journey for designers look like?



Initial Problem definition Asset 1@3x.png

The first priority is to introduce the new knowledge, delight them(the learners) such that they can connect to the subject and understand it based on their experiences.

The activity cycle shown in the image on the right is based on Kolbe's learning cycle discussed in section 2.3.1.

The time limit considered for the entire activity is 6 hours i.e 4 hours of exploration, thinking, designing and 2 hours of 3D printing.

The image on page 50 illustrates the activity cycle designed for the workshop.

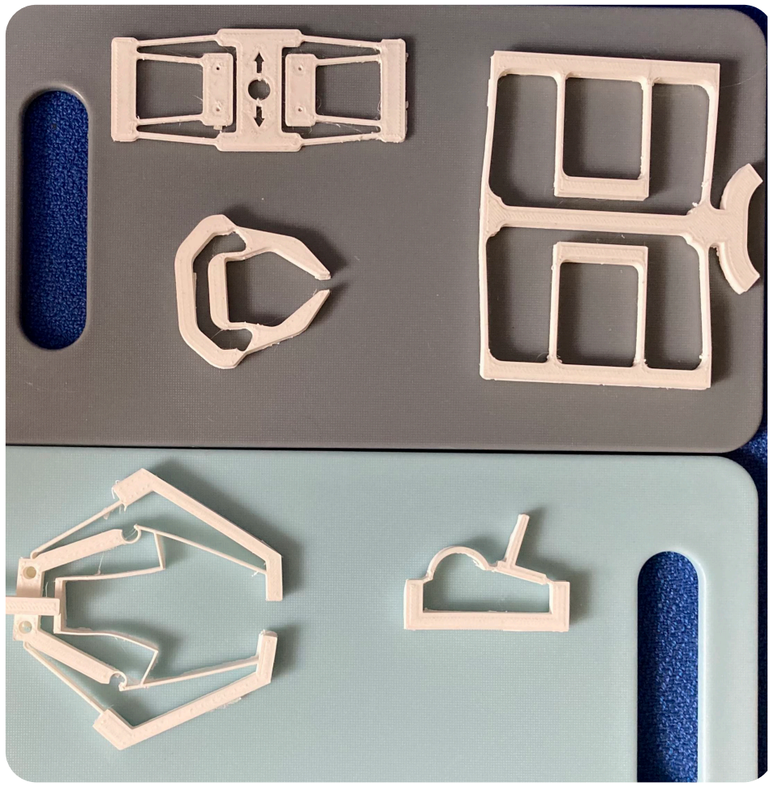
4.
Develop

This chapter focusses on building on the goal and vision of the project. The first activity would be a co-creation session following with a workshop for student product designers. Finally the workshop that is designed is taken to a company setting where it's value is further understood and future directions are discussed.

4.1 Building demonstrators - Raising awareness and understanding through playful interactions

From the earlier **discover** chapter the importance of demonstrators are outlined. In this section, the library of mechanisms would be translated into physical 3D printed demos for product designers to interact with as an early stage activity in their learning journey to understand the principles of flexible engineering.

The 3D printed demos comprise of compliant elements, translational mechanisms, bistable mechanisms, flexure based gripper mechanisms and product examples.



Examples of demonstrators

4.2 Designing the co-creation session

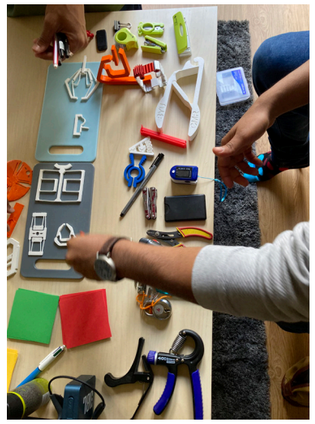
1. Observing a compliant design - Write down observations
2. What's in the bag and why? - What product have you got?
3. Explore - Play with Demonstrators
4. Why do you think it is relevant to us - product desingners?
5. What mechanisms are you inspired by in nature? - Go out and explore
6. Come back and share
7. What would you want to make? - ideation - no judging - (constraints - 3D printable in 2hours - 3 hours) - Stationery - kitchen ware - tools - mask - etc - 20mins
8. Selecting the object that needs to be designed
9. List out elements - rigid bodies, flexures etc
10. List out elements - rigid bodies, flexures etc
11. Part synthesis - How many parts are there to your design? How do they come together? Are some of them integrated?
12. Kinematic synthesis - How do they move? - Show parts that don't move
13. Sketch 2D
14. Extrude in CAD and optimise for 1.5 hours of 3D print max
15. Send to 3D print

4.3 Co-creation session

Participants engaged in activites in the workshop

4.3.1 Introduction

In order to understand the workings of a workshop the topic of designing using flexures is first introduced via a co-creation session.
3 participants are recruited for the session. The total time considered for the activities is 4 hours.
The activities are as planned in section 4.2.
The goals of the co-creation session is to introduce topic, invite discussion, design something tangible and 3D print the design so that one design iteration is done.



Interacting with demonstrators

Exploring ideas through paper cutting

Developing geometries to explore movement, functions

4.3.2 Session

The session was conducted in a friendly environment. All apprehension and tension about the topic was put to rest by making the session explorative and conversational. The participants discussed each topic together. The participants were asked to bring along a small product that they could discuss and possibly make a flexible/compliant version of the same product.

During the session, a flexible design was observed and each observation was noted down in sticky notes. The demonstrators were mostly used as reference points. They gave a very tangible understanding of compliant mechanisms at large.

Discussions relating to the relavance of flexures in product design were conducted after which mechanisms in nature were observed.

The idea was to draw inspiration from nature to design geometries that would aid in flexible design.

Following this activity, the participants were guided to the design phase of the co-creation session where the objective was to end up with a tangible outcome.

One of the participants took to paper cutting his 2D synthesis of his product. Considerable amount of time of 1hr was spent on synthesising in 2D then 3D CAD was used to make a tangible outcome.

It was observed that 4hrs was too little to get to a tangible outcome. The participants concluded that a guiding document would have helped them tremendously in speeding up the process of design.

4.3.3 Results

Result 1

Result 2

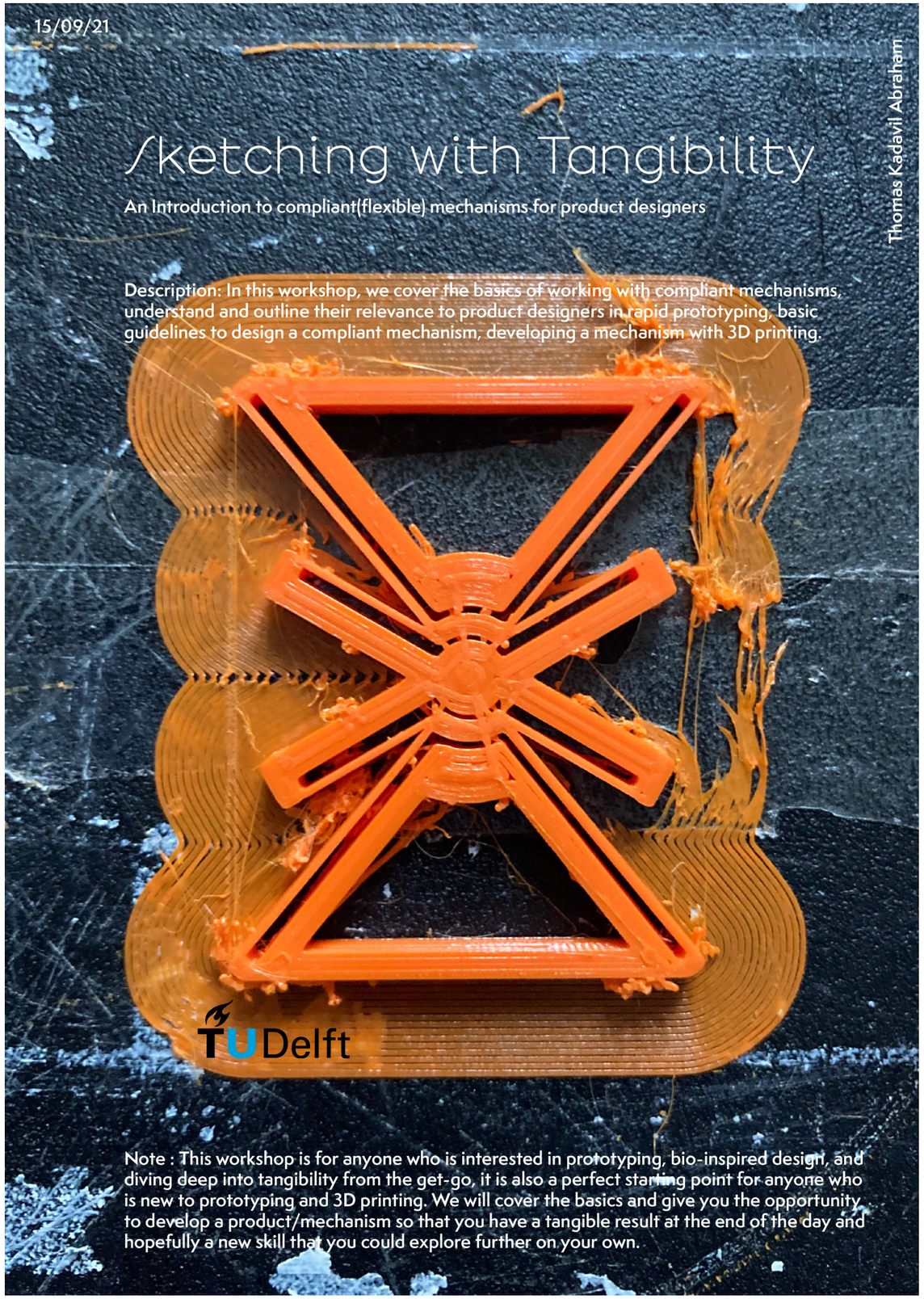
To understand the experience of the participants, an exit survey was used(Appendix G). From the survey we understand that the participants liked the structured process and it definitely helped them in getting a better understanding of the topic and implementing it in their first design. The level of engagement as reported by the participants was more than 80% of the time. On enquiring what could have been done better, bioinspired geometries could help in more design ideas.

Results 1 and 2 in the images above shows the end result of two of the participants.

Thus the session was able to educate designers on the new topic in a fun and enjoyable manner, the results could be better and faster if there was a guideline that would aid more autonomy in learning. Following the co-creation session, a guideline was outlined as seen in section 4.4.

4.4 Guidelines for designers

- *Establish how many parts your product would have(Part Synthesis).*
- *Identity which of these parts would move and which of them would be stationery(Mechanism Synthesis) - Draw a rough 2D sketch.*
- *Make parts that are stationary - thick and the flexures/parts that need to move - thin. (Flexures are thin members).*
- *Replace revolute joints with flexures(Rigid Body replacement).*
- *A rule of thumb of 1:5 is to be followed here(thin flexible part 1mm : thick rigid part 5mm).*
- *Make a paper cut model of your 2D design(gain further clarity on your flexible and rigid parts and kinematics of the product)*
- *Put in dimensional constraints on your product(start with something that is printable in 1 hour, it's always scalable)*
- *Make a 2D Sketch in CAD*
- *Translate the sketch to 3D in CAD.*
- *3D print the design.*
- *Apply intended force and interact with your product/mechanism.*
- *Evaluate and re-iterate.*



Workshop poster for gaining interest

4.5 Workshop IDE Academy

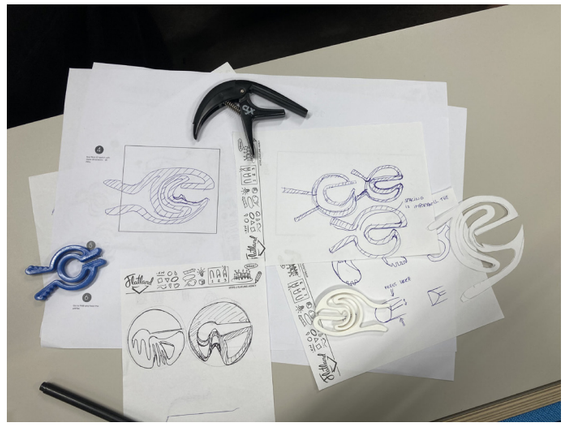
4.5.1 Introduction

The next step in the project was to introduce the workshop to product design students through the IDE academy at TUDelft. In order to inform the students about the workshop a poster was designed as seen in the image to the right. The workshop had 38 participants who had no prior understanding of the topic. The aim of the workshop was to introduce the topic in such a manner that the participants could later use the understanding in their own prototyping endevours. The workshop needed to be fun and hands on so that their learnings could be reflected upon at the end of the day. 8 3D printers were requisited at the PMB lab for the participants.

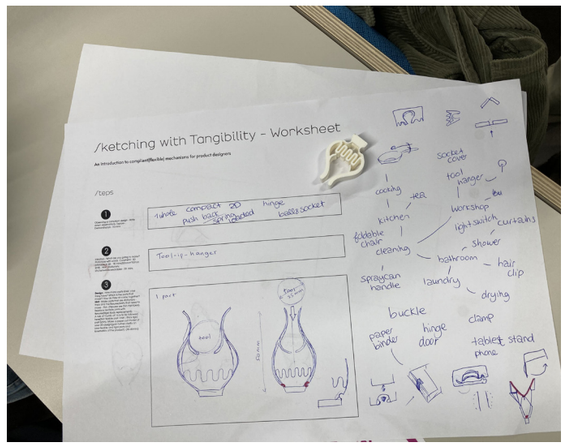
4.5.2 Session

The session had the following schedule in place, introduction(30mins), designing(2.5hrs), break, 3D printing(2 hours), reflection(30 mins). After the short introduction, the participants were invited to explore the demonstrators comprising mainly of revolute and prismatic joints. They were also given examples of products such as a guitar Capo and a carabiner made from a single part. The presentation was used to make the approach of compliant mechanisms relevant to designers. The demonstrators played the role of a tangible learning experience. The participants were then asked to form groups of 5 and start work with the worksheets. The worksheets helped the participants to focus on small to dos to get a valid end result. The guidelines were integrated into the worksheets in the form of hints.

Students in the workshop exploring demonstrators



From 2D to 3D printed mechanism



The worksheet being used to create a compliant mechanism

Two examples of how the worksheets were used to get to a valid result is illustrated in the images above.

/ketching with Tangibility – Worksheet

An Introduction to compliant(flexible) mechanisms for product designers

/teps

1

Observing a compliant design - Write down observations. Explore - Demonstrators - 10 mins

2

Ideation - What are you going to make? Prototype with wires. Constraint - 3D printable in 60 - 90 mins(50mmX50mm approx) - limit - Stationery, kitchenwares,wearables - 20 mins

3

Design - How many parts does your thing have? Which is the parts that moves? How do they all come together? **Hint** - Make parts that are stationary thick and the flexures/parts that need to move - thin. (Flexures are the members). Replace rev/sub parts with flexures(Rigid Body Replacement). A rule of thumb of 1.5 is to be followed here(thin flexible part 1mm - thick rigid part 5mm). Make a paper cut model of your 2D design/gain further clarity on your flexible and rigid parts and kinematics of the product?. (30-40mins)

4

Your final 2D sketch with clear dimensions - 20 mins.

5

Make 2D sketch in a CAD software - Extrude it - Send to CURA to slice. - 20 mins.

6

Go to FMB and feed the printer.

7

Now you have your compliant thing, what do you think about it? How was the process? Did you enjoy it? What didn't you enjoy? What could have been better?

Sketching with tangibility worksheet

Sketching with tangibility worksheet

4.5.3 Results

Feedbacks were requested from the participants, out of 36 reviews 33 participants found the workshop useful and were happy with what they learnt. The workshop being hands-on helped in the better understanding of the participants.

The workshop resulted in 7 of the groups getting a fully functional working prototype, designed in 2.5 hours, some earlier. It is noted that the group that didn't get a favourable result tried their hand at a bistable mechanism that wasn't covered in the demonstrators provided, neverthless the process did lead them to learn about the subject in about 2 hours of time.

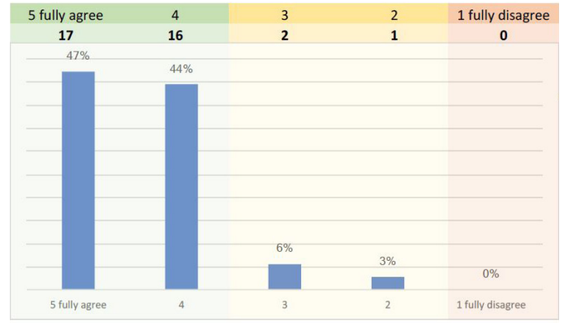
The demonstrators were used for an experiential understanding of the principle, worksheets helped the learners follow a learning curve at the same time allowing them to maintain their autonomy in the process of design. It was also noted that performing in groups helped in conversational learning and help build confidence in the subject in a small amount of time.

IDE ACADEMY

QUIZ FEEDBACK: SEP 15 SKETCHING WITH TANGIBILITY

Score Distribution

The workshop helped me to get (more) familiar with the topic:



Respondents		*Attendees*
36	/	38

Avg. Score

4,36

Feedback on the workshop

IDE ACADEMY

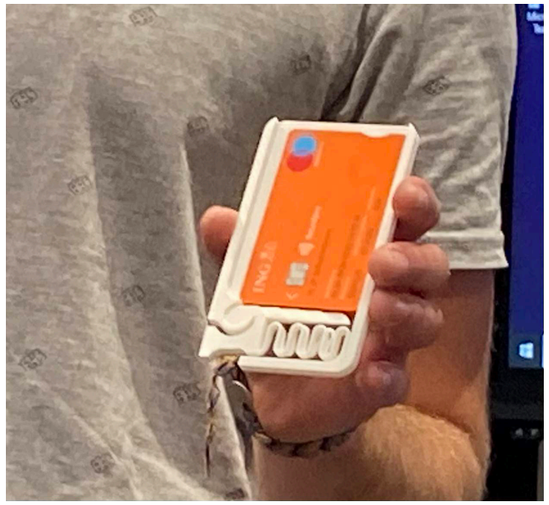
QUIZ FEEDBACK: SEP 15 SKETCHING WITH TANGIBILITY

Comments

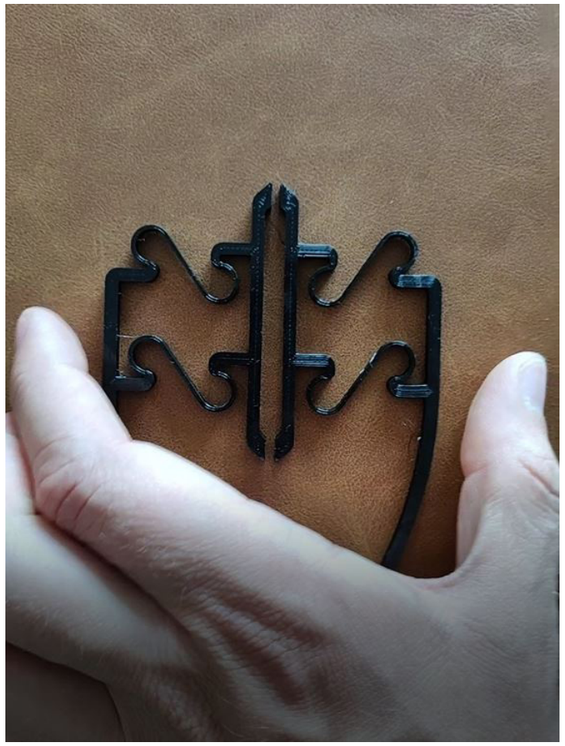
Any comments, tips or compliments for the workshop facilitator and/or the IDE Academy staff?

Learning how to design compliant mechanisms and seeing practical examples of them
Building your own mechanisms
Really nice that we learned the basics of compliant mechanisms in one day!
Getting to the rapid prototyping
Seeing that designing and printing your design in just a couple of hours can actually give you a working product. Also that you experience how complex mechanisms can be translated into something simple, made from one piece.
making the designed part with the 3d printer
Making a fully functional design. It came out well and the assignment was doable in the time given. Also very fun.
Very hands on workshop and it was great to see the results at the end and see what other groups came up woth
actually prototyping and printing in one day
Prototyping
getting to print your own design and test it
Getting to make our own design
Printing it yourself
Hand on workshop
Actually printing it and landing on a great design! (Pass holder)
Seeing the actual results working
One of the best ID academy workshops I've followed! (And I've already done 10). I really liked that within 1 day we could learn about these mechanisms and immediately apply it into our own tangible design
That we got to design and make something from start to finish in a day, really fun
You are really challenged to think it out by yourself
Seeing all the examples of tangible products
Making things, prototyping
Really practical
The modelling and 3D printing
sketching and seeing what was achievable in one day
Getting to know new methods for compliant design
Designing a mechanism yourself
having a first introduction with existing complient mechanism instead of digital
it was fun to thinking about different solutions to replace multiple moving components with parts consisting out of one piece and one material.
The enthusiasm of the person that gave it, he had a lot of energy and had not trouble motivating people
Being able to 3D print for the first time, and discover compliment mechanisms
Getting a working product is really satisfying. It is really inspiring. I'm excited to try making something like this again
That our design worked!!
Hands on session! Best way to learn, trial and error process and gives a better feeling. Would've been nice to do an iteration but we were just a bit too slow I guess :)
Being able to design and print/test our own mechanism

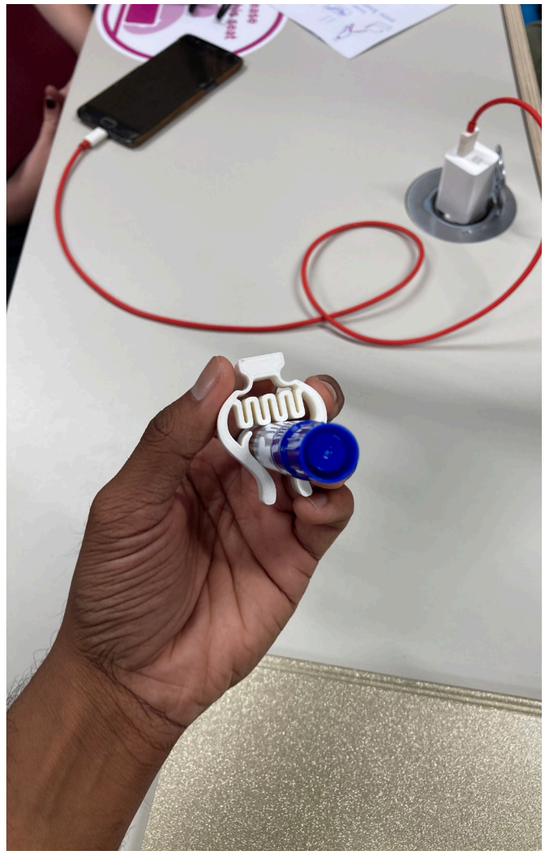
Feedback comments from students on the workshop



Example of a flexible card holder



Example of Compliant tweezers



Example of flexible tool holder

“A very hands on workshop, it was great to see the results at the end, also to see what other groups came up with”

“Learning how to design and experiencing compliant mechanisms helped”

“We got to design and finish in the same day! That was really fun!”

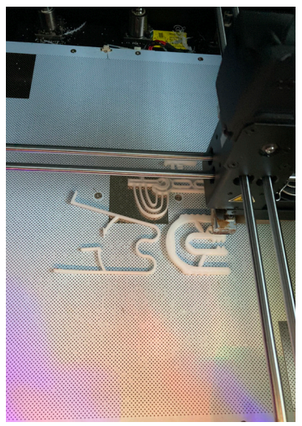
“The enthusiasm of the person who gave the workshop, he had so much energy, he had no problem motivating people ”

“Really nice that we learnt about compliant mechanisms in one day!”

4.6 Workshop /tudio Mango

Professional designers exploring demonstrators

Creating 2D sketches and extruding to 3D



3D printing the mechanisms

4.6.1 Introduction

After introducing the approach of flexible engineering to design students, it was time to see if professional designers appreciated this as much as the students at the university.

The workshop was setup very similarly as the one with the students but this time around we had a time limit of 3 hours. Another constraint that we faced was that there was only one 3D printer available.

It is also noted that the abilities 3D modelling of these learners may be better than that of the students.

4.6.2 Session

The session started with an introduction, after which the demonstrators were provided to the designers for about 15 mins. Worksheets were provided soon after, 3 groups of 4 were made. About 45 mins was spent on designing from paper to CAD. The next 1 hour was spent 3D printing. Once the results were obtained, the team was asked for their feedback via a questionnaire (Appendix J) and informal discussions.

4.6.3 Results

The results of the workshop are as seen in the images to the right. What can be observed is that the designers had total freedom in designing from scratch and were able to develop novel ideas and test out their functionalities.

The workshop was regarded as fun and a good team building activity. On enquiring about how it could be developed on further enabling them in their design practice, it was noted that a technology guide and a material guide could bring in a lot more value and actually help them implement their ideas at scale.

Result 1

Result 2

Result 3

5.
Deliver

This chapter focusses on discussing the different elements of the workshop that contributed to it's success, enlisting the limitations it has and how it could be overcome. The possibilities of a business are discussed and further recommendations for Borderless Quadrant are given.

5.1 Elements of the workshop

The workshop elements that contributed to its success were the following :

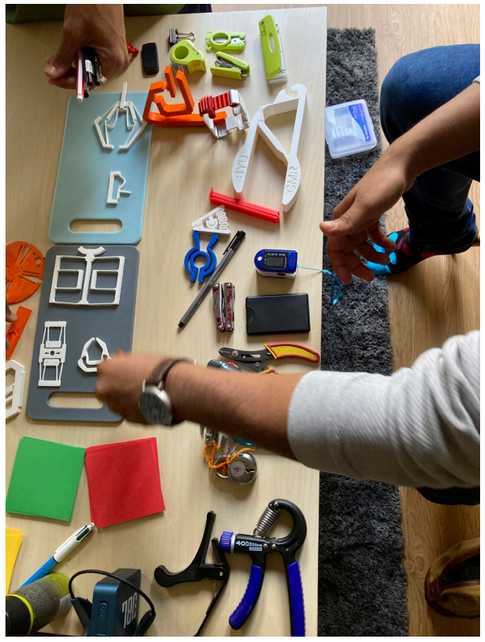
Time
Based on the context of the workshop, the time that would be afforded for the workshop would vary. It is important that the workshop is paced so as to provide a sense of momentum and progress. This could also add some amount of eustress to the participants.

Timing activities can improve the pace and provide momentum

Demonstrators
Were a big part of the workshop experience to provide the participants with an experiential understanding of the principles being taught. This formed the first and very basic understanding on the subject.

Worksheet was modelled around the experiential learning framework, it posed questions so the participants couls think on their own and form opinions about what they thought their design should loook like. It helped them have full total control over their learning journey. The hints in the worksheet helped them grasp basic concepts.

A **Tips and tricks** guide was also added after observing how professional designers designer their products. This outlines three very basic concepts concerning with introducing movement between parts, storing energy and distributing stresses.


Demonstrators at work at one of the workshops

3D printers played a very important role in the workshops by facilitating the tangibility aspect and to provide material for the learner to reflect upon.

The role of the **facilitator** is not to be the expert on the subject but rather to question and observe the learning process in the participants. This allows the facilitator to ask relevant questions pertaining to the individual problems the learners are facing in their learning process.

/ketching with Tangibility - Worksheet

An Introduction to compliant(flexible) mechanisms for product designers

/teps

1

Observing a compliant design - Write down observations, Explore - Demonstrators - 10 mins

2

Ideation - What are you going to make? Prototype with words, Constraint - 3D printable in 8h - 90 mm(80mmm*50mm limit) - Hint - Stationary, kitchenwares,wearables - 20 mins.

3

Design - How many parts does your thing have? Which is the parts that move? -How do they all come together? **Hint** - Make parts that are stationary - thick and the flexures/parts that need to move - thin. (Flexures are thin members) Replace revolute joints with flexures(rigid body replacement). A rule of thumb of 1:5 is to be followed here(thin flexible part 1mm - thick rigid part 5mm). Make a paper cut model of your 2D design/gain further clarity on your flexible and rigid parts and kinematics of the product). (30-40 mins)

Worksheet incorporating the experiential learning cycle

4

Your final 2D sketch with place dimensions - 20 mins.

5

Make 2D sketch in a CAD software - Extrude it - Send to CURA to slice - 20 mins

6

Go to FMR and feed the printer

7

Now you have your compliant thing, what do you think about it? How was the process? Did you enjoy it? What didn't you enjoy? What could have been better?

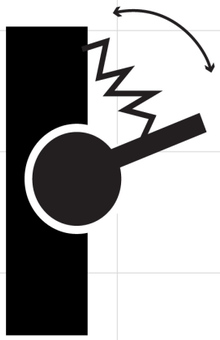
Worksheet incorporating the experiential learning cycle contd

/ketching with Tangibility - Tips and Tricks

An Introduction to compliant(flexible) mechanisms for product designers

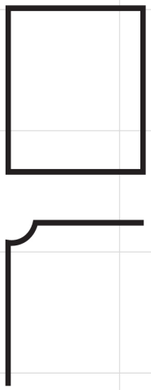
1

To introduce movement between parts one way is to make pivots.



2

Stress distribution between parts could be aided through a curve.



3

Energy could be captured with the use of hooks, stoppers.

Tips and Tricks

3D FDM Printer

Me being the workshop facilitator

5.2 Discussions and future possibilities

Through the course of this project we've learned a few things about how this approach(flexible engineering) is beneficial to product designers. One of the main things is freedom to design from scratch instead of depending on external components for providing movement in a product. Mechanisms and materials, have previously been a black box that designers could only choose from . The approach of flexible engineering gives designers tools to make much simpler products and in fact integrate the form and function of a product. The emergence of 3D printing has paved way to a wider range of on spec materials that give a lot more freedom to achieve the desired results. Time lags in a design project due to sourcing parts could be avoided. Better clarity on the early stages of prototyping could be achieved using this approach, this helps in innovation to take place at a much faster pace. The deductive approach to product design could be overcome through this approach because of part integration that is facilitated by adopting a compliant design. By ensuring the homogeneity of materials in the design, recyclability of the product becomes much easier.

This project has barely scratched the surface on what's possible with 3D printing. There are myriad of technologies available and through this project only FDM printing has been explored. Various other technologies such as 3D fusion technology could be explored.

Only the aspect of prototyping was explored in this project, the world of producibility remains to be explored.

It becomes easier to emulate nature in its functions by adopting a flexible product design. This technology provides the bridge to more bio inspired designs.

From a mechanical engineering stand point, the products could be designed based on the force displacement curve requirements rather than just relative motion between parts.

All in all this project introduced a more holistic approach to design which resulted in products not being a sum of parts.

More value could be provided to designers by guiding them through different technologies within the 3D printing space. A material guide could help shine more light on how to go from a prototype to a design for production.

The bridge between designing with origami and compliant designs still needs to be crossed. An insight to this could help move in the direction of more freedom for designers.

5.3 Business Potential for Borderless Quadrant and recommendations

In section 1.5 clients and stakeholders, Borderless Quadrant was introduced as a mock business entity to account for business values and goals of a company.

Now, at the end of the project, the values of both stakeholders i.e the IDE academy and borderless quadrant have been upheld. The mock business entity could very well become a small business.

Through the course of this project many people have expressed interest in this approach and the workshop. I have been invited to 3 organisations already to conduct a workshop.

This proves the potential value it holds for a myriad of people.

In addition to the potential of conducting workshops for various organisations, a toolkit with a process and a material guide could help introducing a new channel for providing value.

In unlocking the potential of the internet an online blended learning experience could be curated for netizens who are interested in this topic, thus catering to individuals and not only limiting to organizations.

Collaborations with artists and studios to develop novel products and artifacts could help educate more people about this approach to design.

Through this project, borderless quadrant has been able to prove that anything could be learned and learning experiences could be fun.

This same approach could be used in simplifying technology research from various domains in order to make it more accessible for designers. This could prove to be a big opportunity for this business.

The business of simplifying knowledge and translating it to enjoyable learning experiences.

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Types of Compliance

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