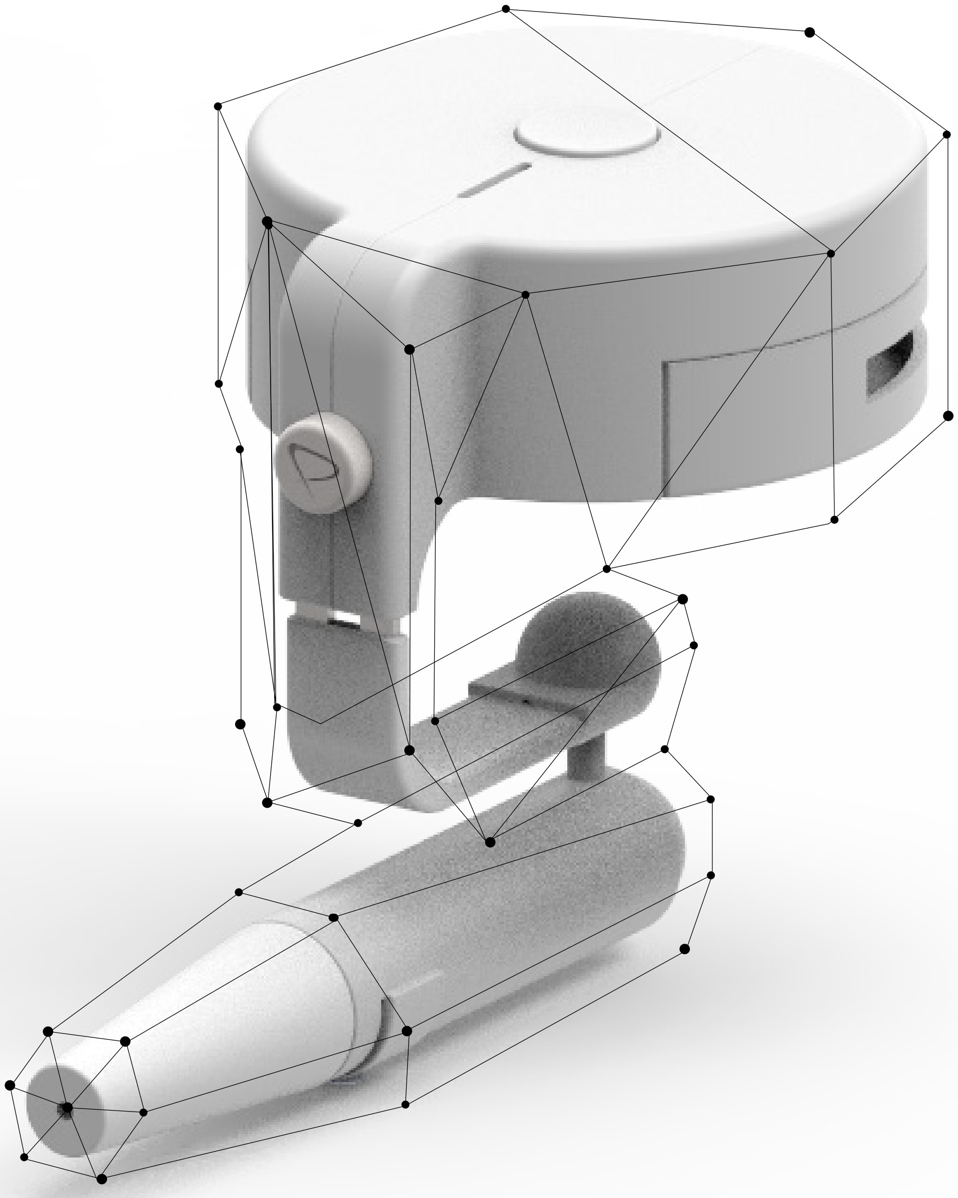
DRAW IN THE AIR

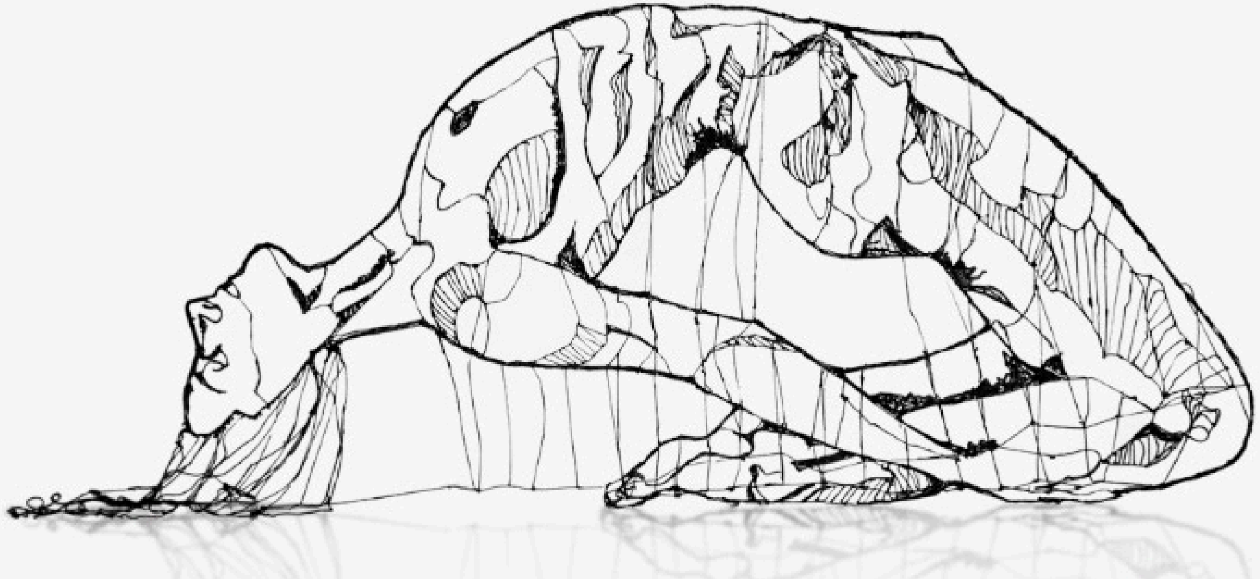
REDESIGN OF 3D PEN



ZHOU RUNSHENG
2017

A flying car
is not just a car that is flying

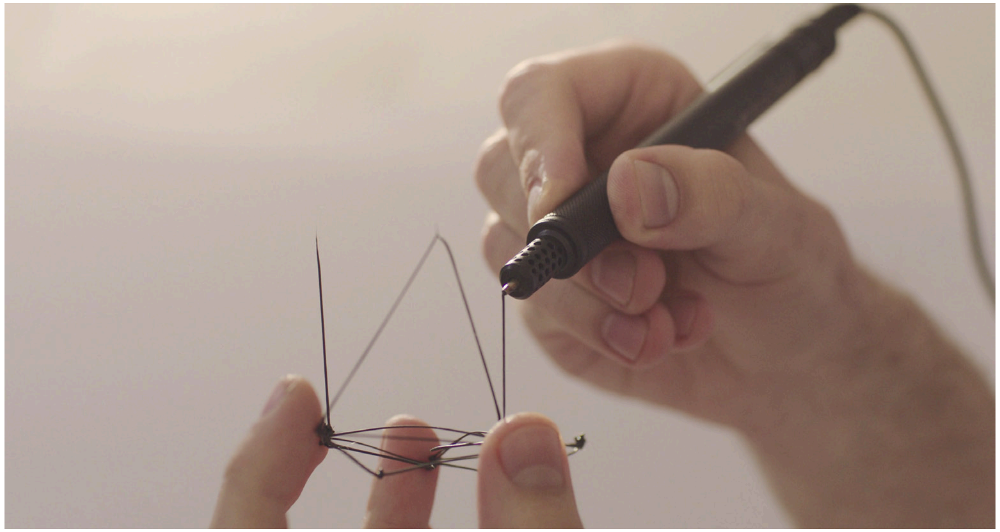
Background



LIX PEN

The project is a company project for LIX PEN, which is a fast-growing start-up from 2014. LIX PEN designs and produces professional 3D printing pen that enables consumers to doodle in the air without using paper, which is the potential to be a perfect tool for architects, designers and all the creative experimenters.

Essentially, the LIX 3D pen functions similarly to 3D printers or glue gun. It quickly melts and cools coloured plastic to create rigid and freestanding structures. The filament (ABS/ PLA) goes through a mechanism while moving through the pen to finally reach the hot-end nozzle which melts and cools it down.



The LIX 3D pen claims to be the "smallest circular 3D pen in the world", which perfectly fits the hand with extreme comfort and natural balance. Different from most of competitors, which creativity ends at only the superb functionality. LIX 3D pen aims to deliver users with sophisticated and attractive design as exceptional benefits, which significantly influences the philosophy of LIX PEN.

The assignment

The assignment is to redesign the 3D pen, which requires the improvement on experience and the results. The product should be designed to bridge the behavioural gap between the tool and the users. Experience will be improved according to deeper research and analysis on users' behaviour.

Contents

Forward

Phase 1

Phase 2

Phase 3

Foreword

Initial methodology

The project is intended to design and introduce a new innovative product based on the current LIX pen. It involves a design process from A to Z, and will finish with the description of design proposal and recommendations towards future developments.

The report will be structured according to the Delft Innovation Model (Buijs,J.A., 2003). It will start at the product-in-use stage, and has adaptations throughout the model as to what has and has not been addressed. The content will focus on the conducted research and analysis, the ideation through an iterative process during the design direction establishment, and product development. Throughout the report design methods and definitions are applied and used, which are described in the literature and terminology appendix for reference.

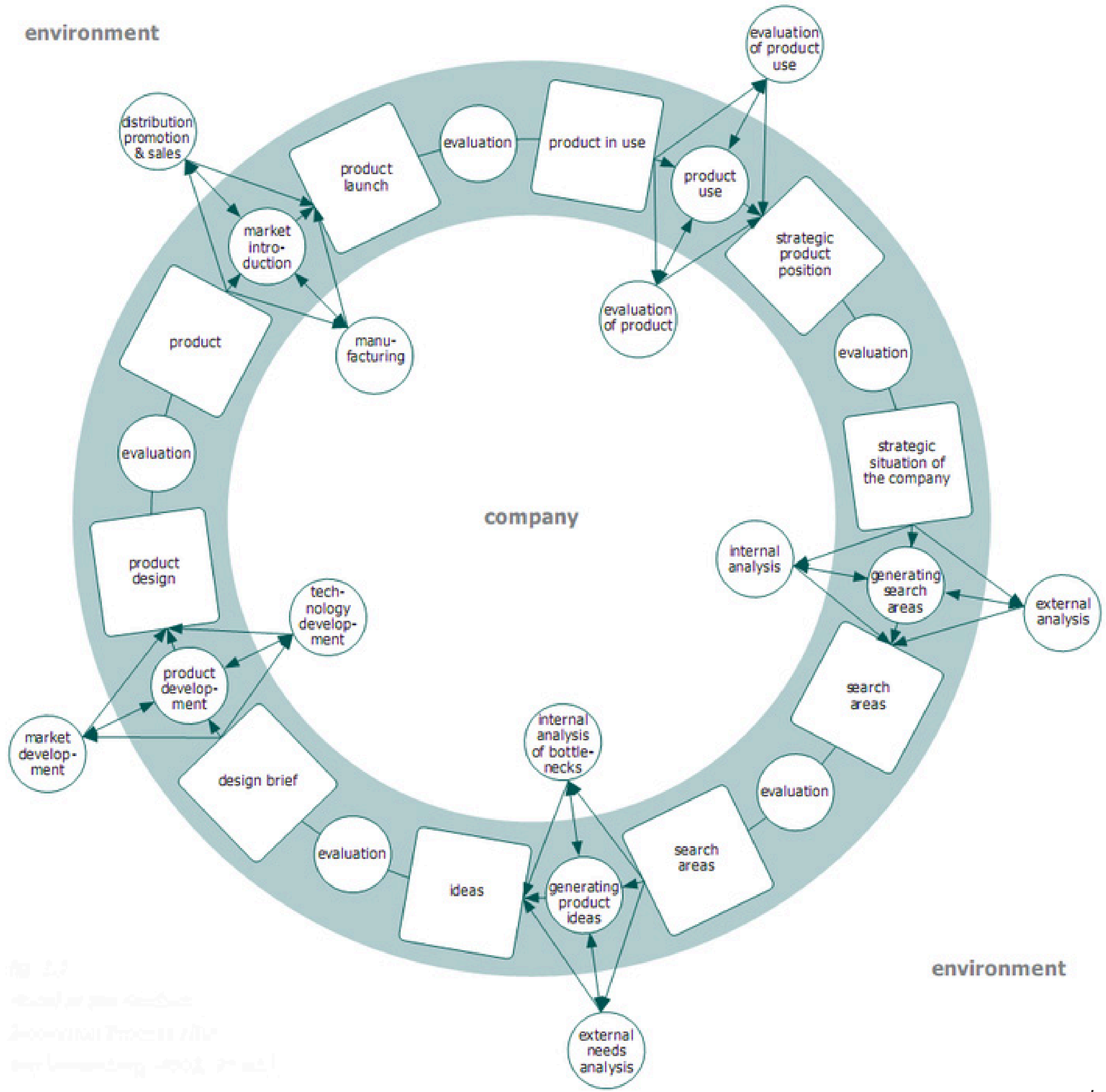


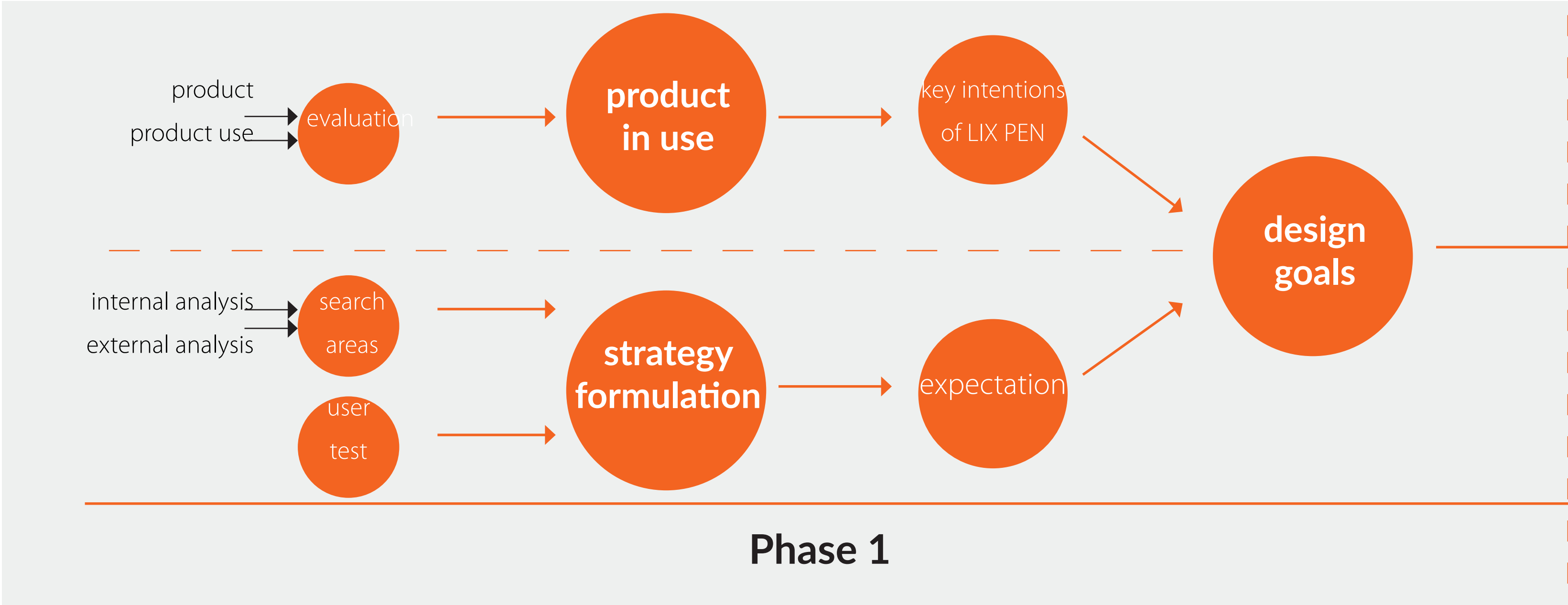
figure 0- 1

delft innovation model

Design approach

Based on Delft Innovation Model (Buijs, J. A., 2003), a design approach that is specific for this project is generated. Necessary and significant milestones in the Delft Innovation Model are retained.

The project starts with evaluation of current LIX pen and will end with a viable product. Entire process is divided into three phases. Those phases are closely related to each other and sometimes conducted at the same time. The different phases are both diverting and converting and will be looped to make different iterations.



Phase 1

For the sake of achieving fundamental design goals, the phase 1 is executed. It involves two parallel approaches.

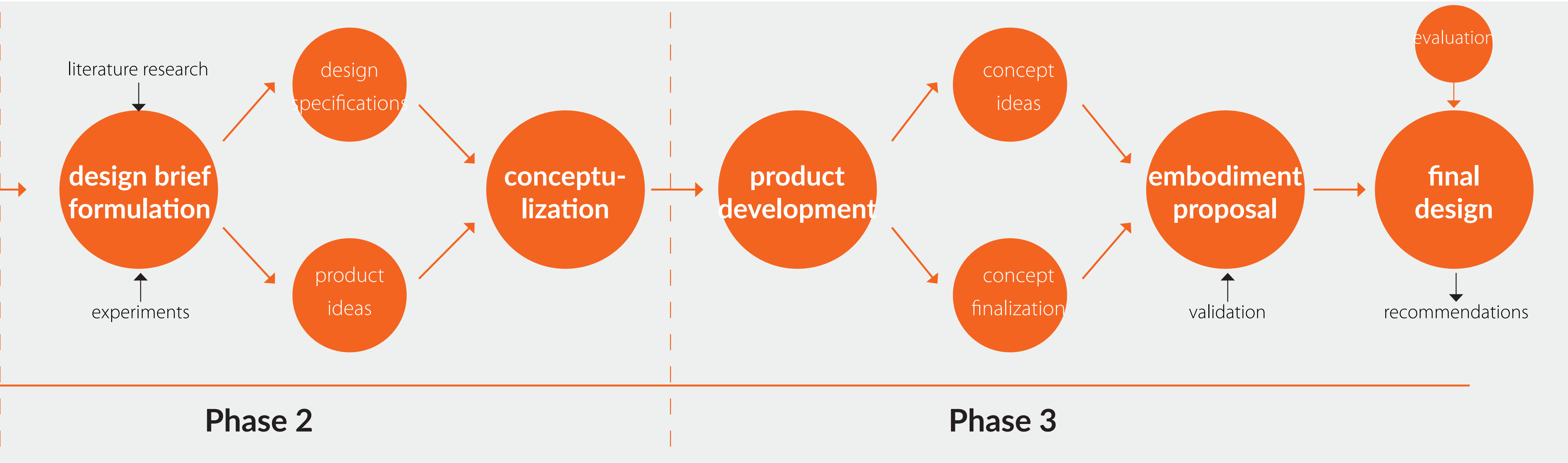
The first approach is product in use. Through comparing the intentions that company want to reach and exact feedback that users experience, key intentions of current product can be revealed. .

The second approach is strategy formulation. It ends up with several expectations that represent potential directions for further development.

Through comprehending foregoing intentions of current product and expectations of future development, fundamental design goals are summarized.

figure 0- 2

design approach



Phase 2

After creating fundamental design goals of the project, design specifications are formulated accordingly. It sets limits to the solution space and indicates which solutions are preferred ones.

Following the formulation of design specifications, the conceptulization of product is done. It is structured from abstract functions of the product to product ideas and the geometric configuration.

Phase 3

In the last phase, foregoing product ideas and geometric configuration are developed into concept ideas and finalized into embodiment proposal.

Based on embodiment proposal, the final design is achieved through a series of validation. According to the evaluation through the prototype, aspects such as operation, ergonomics, etc can be tested. It will finally result into a series of recommendation.

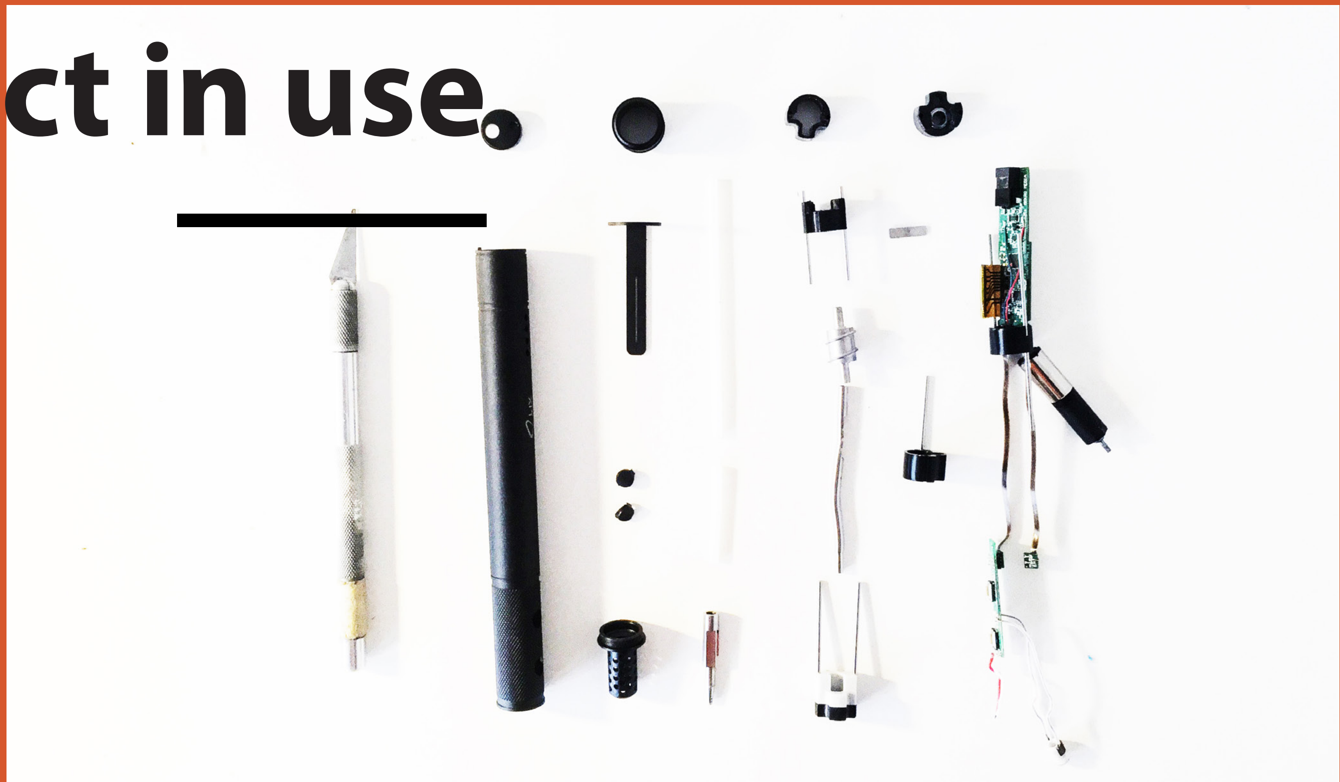
PHASE 1

This first part of the report contains the steps during phase 1 of the project, which consists of the evaluation of the product- in- use and strategy formulation.

COVERPHOTO

LIX PEN official commercial - creating 3D object with LIX pen

Product in use.



Introduction

Based on the Delft innovation model (Buijs, J.A., 2003), the project starts with product-in-use phase, which leads to deeper understanding of current LIX pen.

LIX pen is evaluated by both company, which focus on the evaluation of product, and target users, which aim at the evaluation of product use.

Evaluation of product:
Product is evaluated on both technical view, which reveals the fundamental principle and requirements, and strategic view, which represents the intention of company.

Evaluation of product use:
Product use is evaluated by target users, which indicates current experience of LIX pen.

Through comparing the intentions come from company and exact feedback from target users, key intentions of LIX PEN are concluded.

Evaluation of product

Together with the designer and engineer from LIX PEN, both internal structure and external appearance of LIX pen are analysed.

LIX pen

Origin from 3D printer, 3D pen share the same material and similar principle. The extrusion process is typically linear thermoplastic polymer with certain melting point.

Currently, the filament is conveyed through the motion caused by one thread. The thread is driven by electric motor. Through the friction caused by flight of thread, filament is linearly driven.

Then the filament goes through the melting tube that made of stainless steel. One ceramic surrounds stainless steel tube. Heat that generated by electric heating is successively transmitted to ceramic tube and stainless steel. It entirely functions as the melting mechanism. Basic principle is shown in the figure beside.

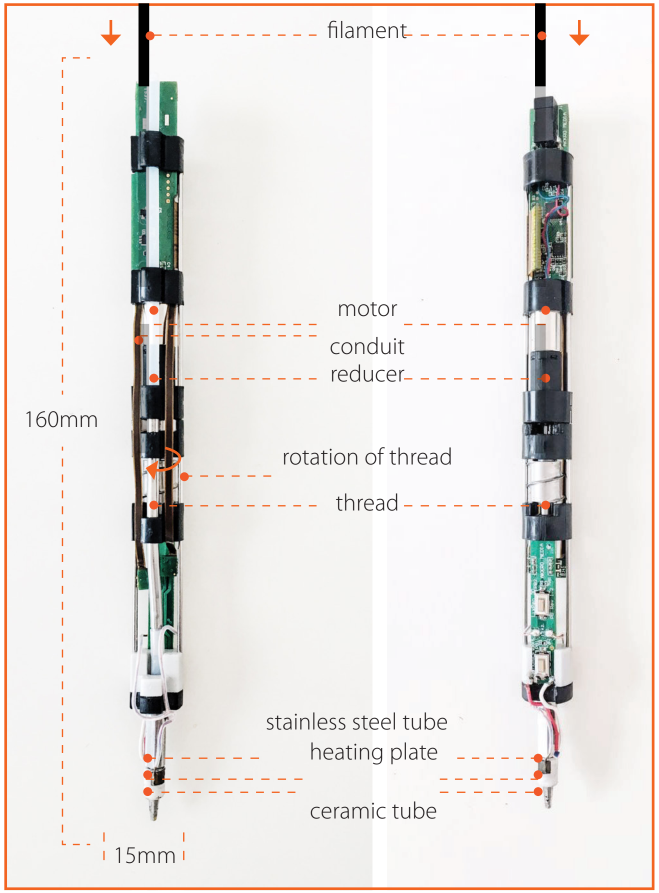


figure 1- 1

Basic principle of LIX pen

Evaluation of LIX pen

Besides basic principle, one explicit evaluation is further made. The evaluation includes both internal and external details of LIX pen.

The evaluation follows the structure that starts from objective forms and properties of each component (Roozenbrug, N. F. M., Edkels, J., 1995). Through understanding exact functions of each form and property, intentions thereof are uncovered accordingly. Afterwards, all the intentions are categorised and grouped into several key intentions. These intentions represent the targets that LIX pen want to reach. (A1, the analysis of current LIX pen). As the result, three key intentions are concluded.

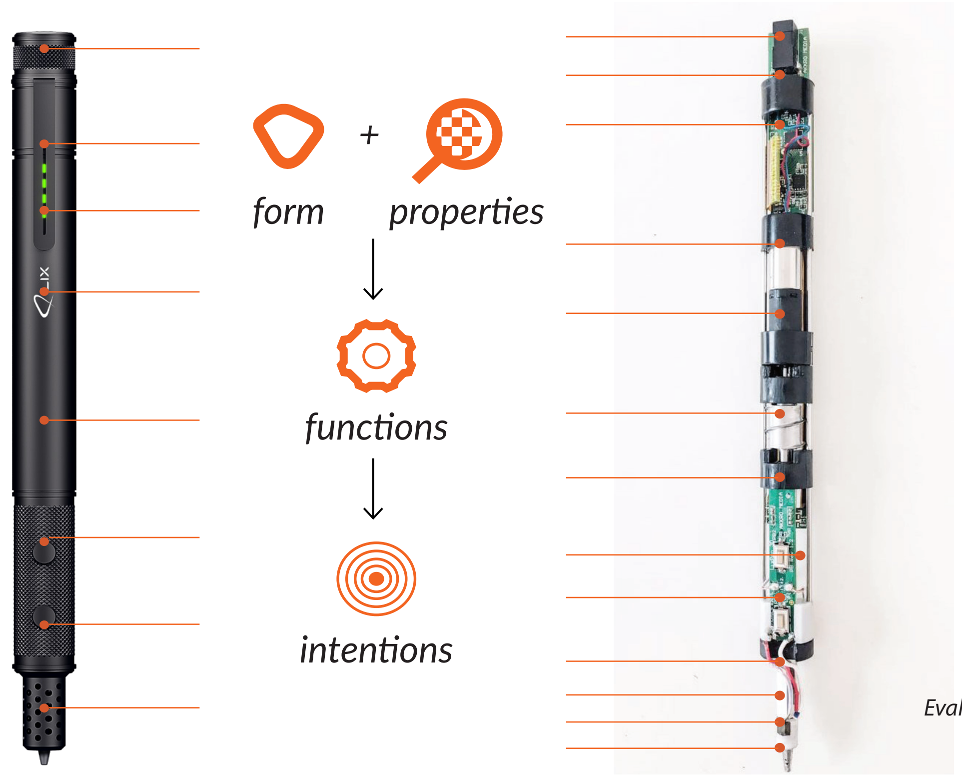


Figure 1- 2

Evaluation of LIX pen

Portability

LIX pen is extremely compact and light through rearranging all the components and configurations. It dramatically enhance the portability of LIX pen, which allows users to conveniently take LIX pen wherever they want. Meanwhile, specific considerations such as adaptable USB charging and additional fixing clip also benefit for portability.

Controllability

LIX pen is designed as similar as possible to normal pen by applying key elements on the product. It increases the degree of familiarity between using LIX pen and users' existing experience, which makes it much easier to directly control the LIX pen.

Comfortability

Alongside the The immense decrease of the dimension and weight, LIX pen is expected to provide more comfortability to users. Furthermore, smooth finishing of surface and special texture on gripping area contribute on comfortability as well.

Evaluation of product use

figure 1- 3

Target users

As previously mentioned in the introduction of LIX PEN (page 5), LIX PEN designs and produces professional 3D pen for architects, designers and all the creative experimenters, which are regarded as target users for this project.

User test

After attaining the key intentions, one user test is performed in order to reveal exact experience of current LIX pen. Accordingly, the rationality of foregoing intentions are verified based on the feedback of the experience. 12 target users are invited to one user test in total. These participants include eight designers from various fields, two architects and two creative experimenters who are into hand craft.

Participants are asked to experience LIX pen without any limitations. During the test, they need to describe the experience at the same time. In the end, all the participants are asked to expound three main problems of current LIX pen.

The test starts from taking LIX pen out of package and ends up with putting it back. Results thereof are classified and analysed based on preparing phase (set up the context), using phase (create objects) and resulting phase (organize results). (A2, transcript of interviews. A3, analysis of interviews)

figure 1- 4

Participants of user test for evaluation of product use

Conclusion

As the result from the evaluation of product, LIX PEN primarily intents to focus on providing controllability when operating current LIX pen, portability that users could take along it as normal pen and the comfortability when interacting with the product. According to the user test, foregoing intentions are verified through whether could they either be perceived or valued by target users.

During the test, the precise and smoothness of operation is highly emphasized by participants, which shows the importance thereof. Both of them are highly related to controllability. It indicates that it is sensible to keep controllability as one key intention of LIX pen.

Comfortability when both holding and operating LIX pen to create objects is frequently mentioned by participant, which is also regarded as one of the biggest problems during the test. It leads the rationality of regarding comfortability as anther intention. Furthermore, the factors that related to portability is rarely mentioned by participants since the test is setted at one fixed position. However, when specifying portability with them, it indeed satisfy participants which act as one important characteristic that product should have.

As the conclusion, all of three intentions that distilled from evaluation of product is verified by user test, which are regarded as key intentions of LIX pen.

Strategy formulation

Introduction

Strategy formulation enablers the finding of search areas which help to find user expectations for developing new product ideas. In this chapter, expectations can be attained according to the combination of the top-down view and the bottom-up view.

Top- down view:

It refers to broad strategic view. Through the insights from both internal of LIX PEN and external analysis of broad trend, core qualities and potential opportunities will be concluded respectively. The combination of quality and opportunities will result in search areas. All the search areas will be evaluated by firstly company then target users, which indicates the common interests from both perspectives. Selected search areas are reformulated into expectations from top- down view.

Bottom- up view:

Particular research will be done specifically for LIX pen. Explicit interviews with current LIX pen benefits on revealing the specific expectations on use-method, functionalities etc. It results in the expectations of target users from bottom- up view.

As the result, foregoing distilled expectations from two views will be unified with key intentions of LIX pen, which result in four fundamental design goals.

Top- down view

Internal analysis: core qualities

Instead of analysing strength and weakness of LIX PEN, internal analysis is altered to analyse core qualities of the product in order to discover core characteristics that is advantageous among various 3D pens. Therefore, a benchmarking against competitors is made. '3D doodler create' and 'Scribbler 3D pen V3' are selected as main competitors based on the approvals of five separate ranking lists. (A4, the frequency of different 3D pens in five separate ranking lists).

The benchmarking is made mainly based on a evaluation by an artist and fashion designer, who is sponsored to evaluate different 3D printing pens. Ranking lists will be supplementary reference of the evaluation. The elaboration of benchmarking can be found in appendix (A5, elaborated benchmarking of three 3D pens).

As the result, LIX pen performs best or equal best in precision of drawing, smoothness of drawing in the air, low noise, proper size and appearance. Meanwhile, as claimed by company, an high-quality image is specially emphasized that distinguish from other brands, which is selected as sixth core quality of LIX PEN.

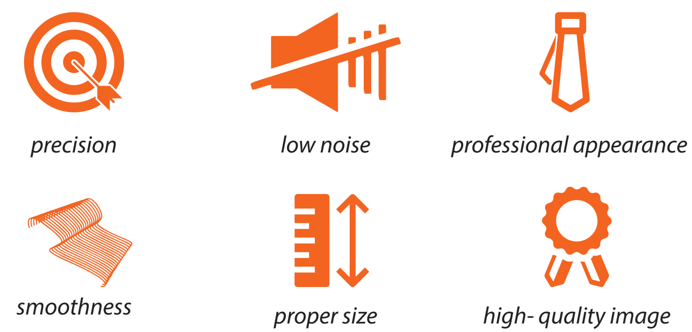


figure 2- 1

core qualities of LIX pen

External analysis: potential opportunities

To better grasp the industry in which LIX PEN are active, a trend analysis is used to create useful trends within different areas of interest. (A6, the trend analysis). The analysis mainly focus on the technology trends, economic trends and socio-cultural trends that are strongly related to this project. Based on the relatedness with the activity that create objects in the air, eight insights that would have most impact are concluded. These insights act as potential opportunities.

Generating search areas

After making an overview of the outcomes from the analyses, potential search areas are formulated. In the overview there will be qualities set out next to opportunities, this to figure out combination that might result into fruitful areas for further investigation. The qualities are results from strategic analyses of LIX PEN. The opportunities are distilled from the trend analysis. As the result, 25 search areas are generated accordingly through a creative session with designers from LIX PEN. All the search areas can be found in the appendix (A7, generating search areas).

Straightforward, search areas are evaluated based

OPPORTUNITIES	QUALITIES
1. As robots and robotics become increasingly pliable, they will fold into our everyday lives in interesting and vital ways. 2. More digital realities will be combined with physical realities. 3. Various craft tools will be integrated into kits for more convenience and efficiency. 4. There will be more things with a colouring theme, such as colourable fabric 5. In the future, people and organizations will want personal mobility 6. As every person is unique, a shift from a standard range of services towards a personalized service in housing, well-being, education, and healthcare. 7. The most valuable companies will connect buyer to seller, or consumer to content 8. More personal disposable means more affordance for relatively high price.	1. Low noise when using the product 2. High precision when creating exquisite objects 3. Proper size of the product 4. Professional appearance 5. Smoothness of drawing in the air when creating in three-dimension. 6. The high-end image with high quality

on the newness and promise of market size. Through the evaluation, ten search areas are sifted out and reformulated into six search areas in the end.

1. Various craft tools integrated into kits with proper size, ensure the portability.
2. High quality components which allow users to DIY
3. Soft robotics to improve the controllability
4. Physical - digital integration to improve the controllability
5. Physical - digital integration with high quality.
6. Soft robotics with high quality.

Evaluation by target users

Foregoing search areas represent the interest of LIX PEN towards future investigation. Following, these six search areas are further evaluated by target users, which narrow the range of further investigation accordingly. Through a questionnaire, 38 participants are required to rate search areas based on attractiveness and newness. Exact research can be found in the appendix (A8, the evaluation of five search areas)

As the result, four search areas are selected accordingly which represent the common interest of both LIX PEN and customers.

1. Various craft tools integrated into kits with proper size, ensure the portability
2. Physical - digital integration to improve the controllability
3. Physical - digital integration with high quality
4. Soft robotics with high quality

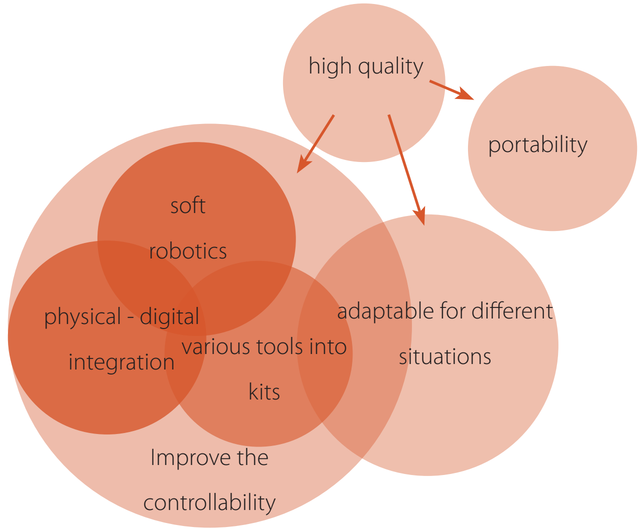
Expectations formulation

Instead of directly immersing in certain search areas, reconstruction of four search areas is completed in order to reduce the implicity. In such way, explicit and concrete expectations from users can be attained accordingly, which are more influential and significant for coming phases.

The figure beside shows the decomposition and recategorization of four search areas. As described by target users, physical- digital integration, various tools integrated into kits and

figure 2-2

decomposition of search areas



soft robotics are emphasized for the sake of the improvement of controllability. Besides, needs for various tools strongly related to the expectation of adaptability in different situations. Thus, physical-digital integration, soft robotics and various tools integrated into kits are reconstructed into the expectations of controllability and adaptability. High quality is regarded as characteristic of other three expectations.

Throughout the research based on top- down view, controllability, comfortability and portatbility, which meet the interest from both LIX PEN and target users, are three key expectations.

Bottom- up view

Besides strategic view, several explicit user tests and interviews are accomplished by target users in order to reveal exact expectations specifically on the activity of drawing in the air.

User test and interviews

12 participants take part in the interview, which specifically aim at the expectations on use- method and expected functionalities. Instead of describing the tool as a 3D pen, the product is introduced as the tool of drawing in the air in order to eliminate the mislead of the word "pen". All the participants are required to physically illustrate expected form of drawing in the air. Then the use are explained by participants (A9, the user tests and interviews about use and expected functions). The figure below shows all of the expectations from participants on form and use-method.

figure 2- 3

Illustrations of expectation on form and use- method of drawing in the air

As shown, ten participants describe the product in a totally different way from current 3D pen, which indicates a gap in between. When explaining the reasons behind, comfortability when interacting with the product and precision of drawing are most frequently mentioned.

Moreover, participants are required to provide at least three functions that they need. Different properties of the output in order to use the product among different situations are extremely needed by participants, which are reformulated into adaptability of the product. Exact analysis of expected functionalities can be found in appendix 9.

As the result, according to the user test, comfortability when holding and operating, precision when creating and the adaptability for various situations are three main expectations from bottom- up view.

Design goals formulation

Sum up the expectations from both top-down view and bottom-up view, controllability, portability, adaptability and comfortability, which act as four main expectations for the product, are distilled accordingly.

Based on foregoing expectations and key intentions from product-in- use chapter (see chapter 1), the ability to control the product and the portability for taking along the product are consistent with both LIX PEN's intention and customers' expectations, which are needed to be either improved or kept.

Comfortability when interacting with the product, which is one of the core intentions as well as expectations of LIX PEN, is compatible with the expectations of target users. However, current comfortability of LIX pen does not satisfy target user through the research, which should be specially considered.

Furthermore, the adaptability of the product is one significant factor that LIX PEN lacks the attention, while customers think highly of.

Alongside the growth of LIX PEN, the product family expands. Several different products are already under preparation, which indicates that it is the proper moment to further bridge the gap in between the needs of target users and functions for adaptability.

As the conclusion, the comfortability, controllability, adaptability and portability will act as four fundamental design goals for following phase.

These four design goals imply the unity of the values of LIX PEN, the expectations on 3D pen both from LIX PEN and target users.

figure 2- 4

Four fundamental design goals

PHASE 2

The second part of the report includes the formulation of design specifications, which act as guidance of concepulization, and the concepulization of the product

COVERPHOTO

LIX PEN official commercial - creating 3D object with LIX pen

Design brief formulation

Introduction

This chapter shows the most relevant process steps after the formulation of design goals. It shows the formulation of design specifications and conceptulisation of the product.

As the starting point, four fundamental design goals are abstractly reconstructed into a series of statements. Through the operationalisation of the statements, a list of normative statements about the properties the product should have are concluded, which act as list of requirements. It sets limits to the solution space and indicates which solutions are preferred ones.

Conceptulisation phase involves one function analysis of the product, which indicates essential functional structure of the product. Solutions, which are aimed at specific functions, are generated accordingly. Together with fore-mentioned design specifications, solutions are evaluated and selected then result in concept idea.

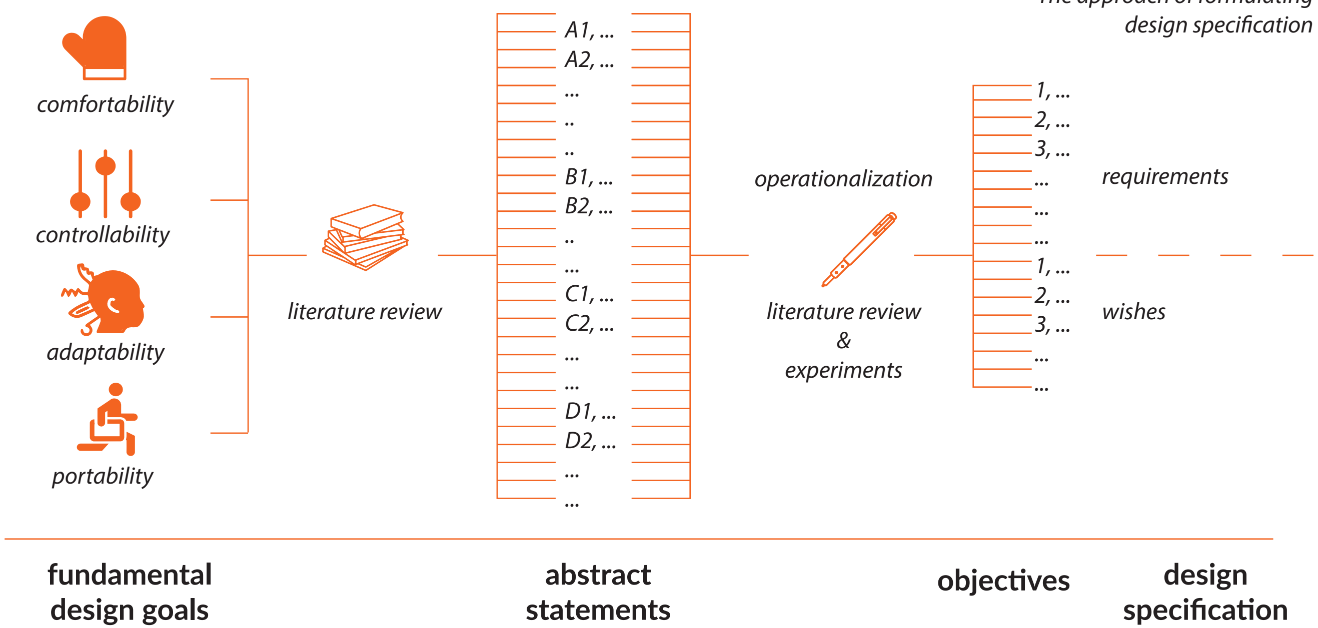
Design specification

A design specification is the elaboration of the goal of the product development object (N. F. M. Roozenburg and J Eekels, 1996). Four fundamental design goals, which stem from previous chapter, are decomposed into a series of statements.

Through an operationalization process, statements are formulated into objectives which are specific for activity of creating three dimensional object in the air. All objectives are differentiated into requirements, which represents objectives that design proposal must necessarily meet, and wishes, which need to be considered. It provides the criteria by which 'value' or 'quality' of the outcomes of designing is to be judged. Synthesizing all the requirements and wishes and formulating them in terms of performance, design specification is created.

figure 3- 1

The approach of formulating design specification



Statements formulation

In order to reduce the broadness and ambiguity, the factors that extremely influence each goal are distilled respectively.

Comfortability

In hand tools, comfort is mainly determined by functionality and the physical interaction between the user and the product (Branton, 1969). Since the strong internal connection between comfort and discomfort, they are regarded as one general concept instead of opposite constructs.

According to Kuijt-Evers (2014), descriptors of comfort/discomfort in using hand tools were collected from literature and interviews. Through statistical analysis, forty descriptors were extracted and mainly distinguished in 6 comfort factors: 1. functionality, 2. posture and muscles, 3. irritation and pain of hand and fingers, 4. irritation of hand surface, 5. handle characteristics and 6. aesthetics (Kuijt-Evers, L. F. M., L. Groenesteijn, et al, 2014). These factors can be classified into three groups which are functionality (consisting of factor 1), physical interaction (consisting of factor 2- 5) and appearance (consisting of factor 6)

As the conclusion, comfortability is decomposed into functionality, physical interaction and appearance.

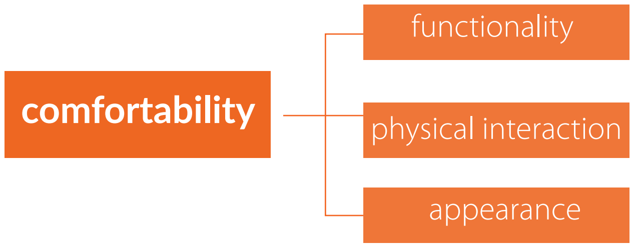


figure 3- 2

Decomposition of comfortability

Adaptability

Adaptability refers to the ability of a product to be adapted to various usages or capabilities (A.Y.C. Nee, 2004). It involves four main factors which are versatility, customization, variety and upgrading.

Versatility is adaptation from one function to another does not require significant alteration of a product. Customization allows users to adjust the product to their preference. These two factors are more important from the usage of the product.

Refer to current design tools and activities, various assistive functions are potential to be added on the product, which requires the upgradable of the product in the future. As one branch that belongs to one series of products, same design elements should be kept among different products, which allows various products share same components to decrease the cost. Below is the objective tree of adaptability.

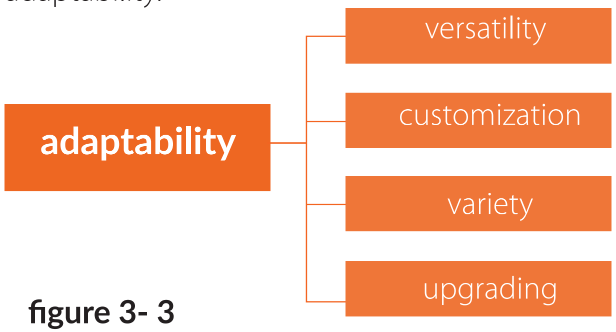


figure 3- 3

Decomposition of adaptability

Controllability

A professional tool requires complex actions in order to control the product, which demands specific considerations on controllability of the product. It refers to the ability for users to operate and interact with product. Previous research revealed users' strong expectation on enhancing the controllability of the product.

Within the design of hand tool, three controllable factors are information achieving, task execution and resulting. These factors are corresponding to three period when using the product. Users should gain enough information to decide what and how to do with product. Then specific experience during the execution of tasks will highly influence degree of controllability. Furthermore, if results fit the expectation will subjectively influence the judgement of controllability.

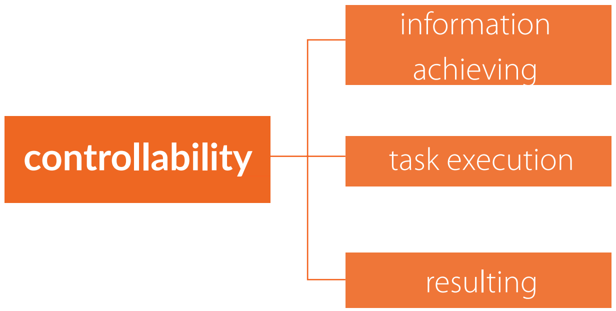


figure 3- 4

Decomposition of controllability

Portability

Various workplaces demand the necessity of portability. It allows users take along the product with them wherever they are going to work. According to Bert Haskell (2015), the principal factors that shape the design of a portable electronic device are as follows: functionality, performance,user interface, form-factor, battery life, reliability, cost and time to market (Bert Haskell, 2015). The last two factors are less important in the conceptualisation of the product, while heavily influence the decision making in later phase. Thus, the cost and time to market will be discussed later on.

Meanwhile, these factors cover all the dimensions of the product, which overlap with fore - mentioned factors from other design goals. In order to specifically focus on the portability, the functionality, performance and user interface are excluded.

As conclusion, form-factor, battery life and reliability are three main factors that mainly determine the portability of the product.

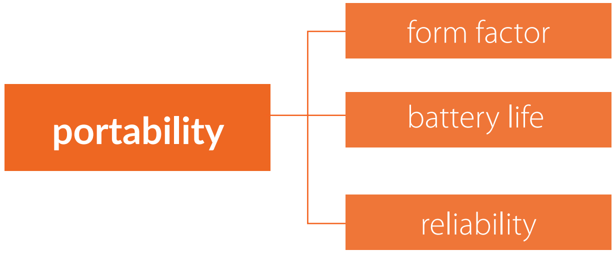


figure 3- 5

Decomposition of portability

Based on foregoing decomposition of four fundamental design goals, each factor is further decomposed into various statements.

As the result, a series means-end chains, which indicate the relations among various statements, are presented. For either one single statement or the combination of several statements, further analysis is made. The full list of statements can be found in the appendix (A10, full list of statements formulation).

Objectives formulation

In order to eliminate abstraction and ambiguity of foregoing statements, the operationalization process, which function as interpreting, clarifying and empirically specifying the meaning of goal-as-intended, is made (N. F. M. Roozenburg, J. Eekels, 1996). Through such process, all the statements are transferred into objectives specific for creating three dimensional objects in the air.

Context analysis

Foremost, objectives will dramatically differ alongside the change of certain context. Therefore, the definition of overall context that the product will be fitted in is needed.

The analysis of context includes an discussion of the object that is created by product and exact motion of creating, which extremely influence the specification of the product.

Three-dimensional object

3D printing pen is designed as the instant 3D printing tool, which enable users directly create three dimensional object. In order to clarify specific definition of three-dimensional object in certain context, various designers are required to list three strongest motivations to use the product after finish experiencing current LIX pen.

As the result, rapid three-dimensional model for the sake of immediate presentation and visualisation is the most common motivation, which was foremost mentioned by interviewees. The research can be found in appendix (A11, the motivation of use 3D pen)

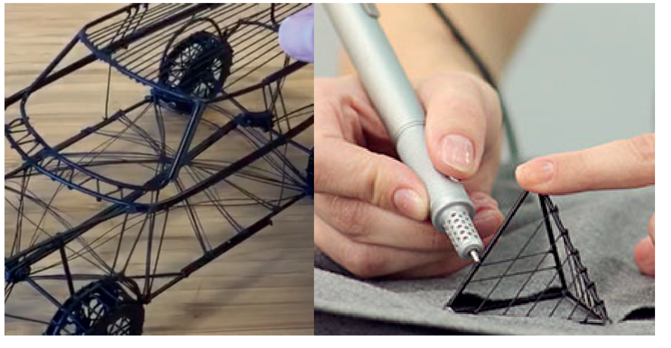


figure 3- 6

Immediate presentation and visualisation

Motion of creating three-dimensional object

As previously described, the main purpose to use the product is creating rapid three-dimensional model. A three-dimensional model is a physical manifestation of a product idea. Three-dimensional model includes different levels of models for the sake of idea generation and communication.

Sketch models are most frequently built among the ideation process. They are tools that are used to visualise the shapes of early ideas. In order to take advantage of the models for exploration of shapes, the shape of model needed to be recognized first. The "shape" we can refer to two quite different properties of visual objects - the actual boundaries and the structural skeleton (Rudolf Arnheim, 1974).

In other words, construction of boundaries of the intended shape and the structural skeleton are qualified for exploring the shapes. Both boundaries and structural skeleton are the assembly of lines. Moreover, line is a track made by the moving points. The process of illustrating a line is actually the process of sweeping continuous point. The points in this project is a series of spatial points.

Moreover, as shown in the figure 3- 7, due to the weak strength of materials, the points that connect different lines are extremely important.

Therefore, visualising the shapes of ideas is transformed into a points sweeping process, which essentially allowing the trace of the tool sweeping a series of spatial points.

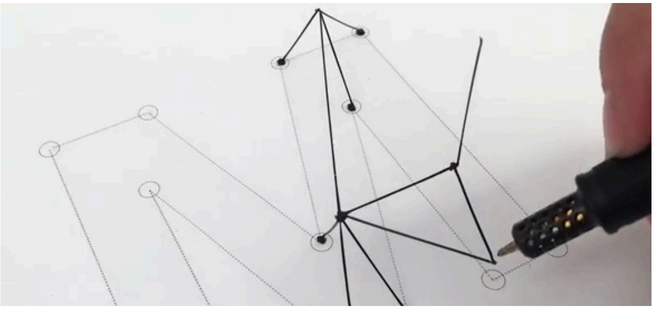


figure 3- 7

Motion of creating of three-dimensional object

Operationalization process

After narrowing the scope of the context, all the statements are interpreted into objectives that specific for points sweeping process.

The operationalization process starts with the reorganization and combination of foregoing statements. Some of the statements are intersected, which can be unified that result in the same requirements. All the statements are further interpreted through either literature analysis or various experiments. (A12, operationalization process of statements) As the result, a series of objectives are generated. In order to make the process to become clarified, one example is given.

Example

In the decomposition of comfortability, there is a statements that is 'the gesture of holding the product should comply with the instinct of users' (A24). Furthermore, there is another statement in the deconstruction of controllability which is 'the form of the product should allow the users to precisely control'. (C5) These three statements are operationalized together since they are all related to the physical interaction when holding and moving the product.

Analysis

Empirically, the target-oriented movement within human-size scale is primarily executed by four limbs of human beings, even though the rest of the body will also benefit the process. Due to the differences of the relative size of the areas in the cerebral motor cortex devoted to controlling the different muscle groups in the human body, different information processing capacity of various parts of the motor system exist.

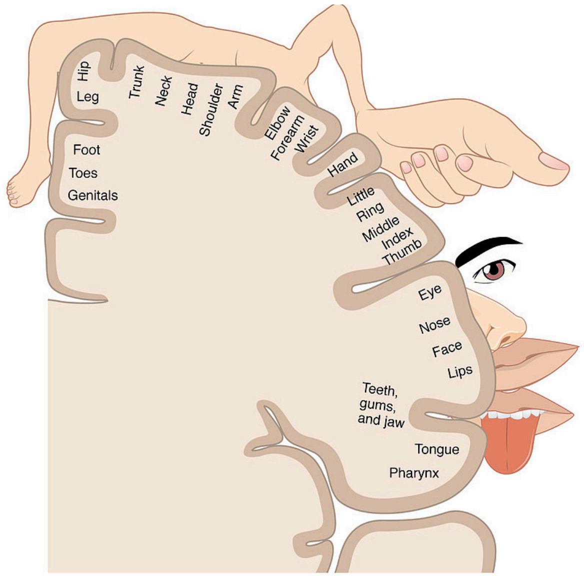


figure 3- 8

Homunculus model of the motor cortex

As the homunculus model of the motor cortex illustrates (figure 3- 8), the muscles controlling the upper limb (hand, wrist, elbow) are heavily represented compared to the muscles responsible for the lower limb. Furthermore, the muscle controlling of shoulder is represented slightly smaller than the rest of the upper limb and roughly same as the trunk and hip, which match the experience that moving the whole upper limb by the joint of shoulder is less convenient or accurate. Therefore, the discussion of upper limb is narrowed into the joint of elbow, wrist and finger.

According to an investigation undertaken by Hammerton and Tickner to see whether there are any differences in the suitability of the different limb-segments, in the most difficult conditions, such as the target size is smaller than 3mm (Since the dimension of current filament in the market, the outcome of the product can be seen as the object within 3 mm, which determine the scope of precision), hand was superior to both forearm and thumb, which indicate higher suitability to the joint of wrist. (M. Hammerton & A. H. Tickner, 1966)

Furthermore, an experiment by Balakrishnan and Mackenzie indicate that the thumb and index finger working together in pinch grip have an information processing rate of about 4.5 bits/s, which performed better than the normal wrist movement (Ravin Balakrishnan & I. Scott MacKenzie, 1997). Therefore, the product is going to be mainly moved by the joint of wrist in pinch grip.

Design specification

Foregoing operationalization of each statements result in a series requirements that act as the foundations of further analysis. All the requirements will be divided into the requirements that the product has to reach and the wishes that the product has better gain. Requirements will be used to set guidance of conceptualization. Wishes are going to be the reference for evaluation of different concepts. Both requirements and wishes are categorized based on use, design and dimension. The numbers correspond to the order in the entire design specification. The code in the end refers to original statement. The most important and influential requirements and wishes will be shown beside. Full list of the requirements can be found in appendix. (A13, full list of requirements).

Requirements

Use

9. The product is handled by moving with joint of wrist in pinch grip. (A24, C5)
10. The posture of holding should be palmar pinch grip. (A25)
11. If there are other components on the hand, the back of hand are the best option. (A25)

14. Users should be able to change the thickness / size of outcomes (B1)
15. Functions of creation and manipulation of colours are needed for different situations (B2, B3)
16. Users should be able to adjust dimensions according to exact needs. (B4)

Dimension

30. The distance between gripping point and the end of finger should range from 60mm to 75mm, while the angle stays around 67°. (B4)

wishes

use

2. Making actions should be as effortless as possible (A6)

design

6. The appearance of the product should be professional for target users (A28, A29)
8. The inner components are preferred to be designed into same dimension and specifications (B6)
11. The product is preferred to be used by bimanually control. (C6, C7, C8)

dimension

12. the size of the product should be as small as possible (A10, D2)

Conceptualization

In this section, the process of conceptualisation is demonstrated. The process is structured from abstract functions of the product to the geometric configuration.

Functions will be persistently divided and product ideas will be generated thereof. Then selected product ideas for each functions will be synthesized. Constraints will be imposed based on the requirements and wishes from previous chapter.

Based on the synthesis of the product ideas, fundamental configuration can be extracted, which supports the following conceptualization.

Function analysis

The core function of the product is creating rapid three-dimensional object through extruding filament. As considered as a technical-physical system, the system's functions are described as a transformation process between a initial state, which is the raw filament, and desired final state of the environment, which is the coloured three-dimensional object.

A consistent whole of sub-functions are developed to describe the main technical process in the product. All elementary and general functions are involved including the by-products and consequences of each step.

Origin from 3D printer, 3D pen share the same material and similar principle. The extrusion process is typically linear thermoplastic polymer with certain melting point. It basically involves five basic function steps, which are dosing, transporting, melting, shaping and solidification. (Zehev Tadmor & Costas G. Gogos, 2013)

Moreover, as previously required in design specification section, users should be able to change the colour (requirement 15), which is another extraneously basic functions of product. In order to transfer this function into technical and abstract functions, the analysis is made first.

Change the colour

Two methods are classified in accordance of applying colour on filament or directly changing the filament with different colours. The component to colour the filament is called coluorizer.

These two methods are compared based on the handling, smoothness of usage, compactness of entire components, cost by customers and the required quality of colouring. As the result, coluorizer prevails over another method except for the required quality. However, due to the product is used to creating three dimensional model which is mostly sketch model, tiny deviation of the colour is acceptable. Therefore, the colourizer is selected as colouring mechanism. Exact comparison can be found in appendix (A14, the comparison of two method of changing the colour)

figure 3-9

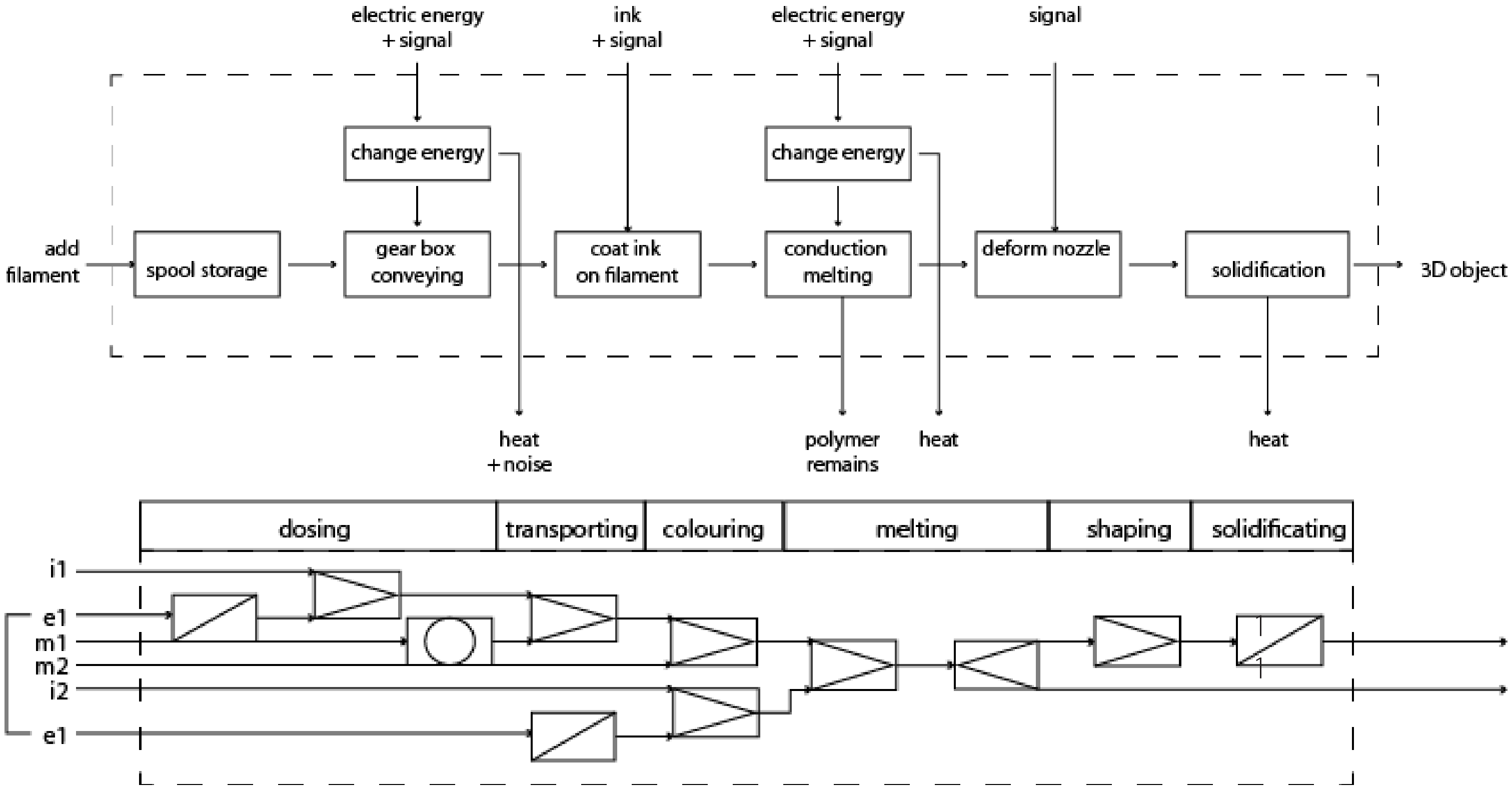
Basic principle of colourizer

Sub-function process

figure 3- 10

sub-function process

The figure below illustrates the sub-function process. The symbols used in last graph is extracted from Pahl & Beitz symbols for general functions.



i = information

e = energy

m = matter

generally valid functions	symbols	explanations
change		I and O differ
vary		I < O I > O
connect		Number of I > O Number of I < O

Explanation of sub-function process

As shown, sub-function process involves six main steps which are **dosing, transporting, colouring, melting, shaping and solidification** of the filament. Function analysis is built as the support of two approaches. Various product ideas can be generated accordingly. Furthermore, the configuration that is distilled will be discussed afterwards.

Product ideas

Based on sub-function process, various product ideas are created respectively. Either one or multiple ideas will be created and discussed specifically for each sub-function. Selected ideas will be explained below.

Dosing the filament

The dosing sub-function involve storing of the filament (2) and conveying the filament (3) to transporting sub-function. Dosing and transporting act as an unity, which are discussed altogether.

Storing the filament

Spool storing, as the most common and popular way for storing filament, act as storing mechanism for the filament. Different from normal spool, it contains a bearing surrounding the hollow cylinder which functions as the axle. Inner empty space of the cylinder is suitable to contain the battery and electric components inside.

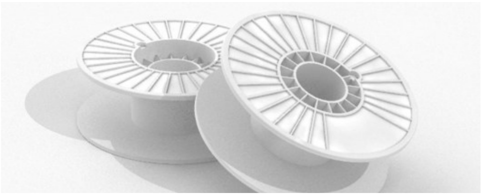


figure 3- 11

Filament spool

Conveying the filament

As mentioned in the product use phase (page 15), current mechanism is screw thread, which utilises the edge of flight to linearly drive filament. There are three sub-functions in conveying mechanism, which are driving the mechanism, reducing the speed of driving and conveying filament.

Currently, one coreless driving motor (figure 12) functions as driving the mechanism. It provides 1.2g*cm load torque and 14g*cm stall torque. The load speed is 16500±10% RPM which conveys filament with the speed of 6mm/s.

figure 3- 12

The motor of conveying mechanism

One specific reducer is configured right next to the thread. It connects the motor and the thread while reducing the speed that caused by motor. The thread and the reducer are considered as a whole which function as transferring rotational motion into linear motion.

Besides the screw thread, transferring rotational motion into linear motion can also be realized by the friction that caused by rotational plate such as gears. Through integrating multiple gears with various diameters and teeth, the speed from motor can be dramatically reduced, which

Integration of multiple gears dramatically decrease the entire dimension while reaching same speed. Moreover, due to the direction of the force that caused by screw thread differs from the direction to convey, it reduce the torque efficiency while gears perform better in this aspect. Therefore, the integration of multiple gears is selected which acts as new conveying mechanism (figure 3- 13).

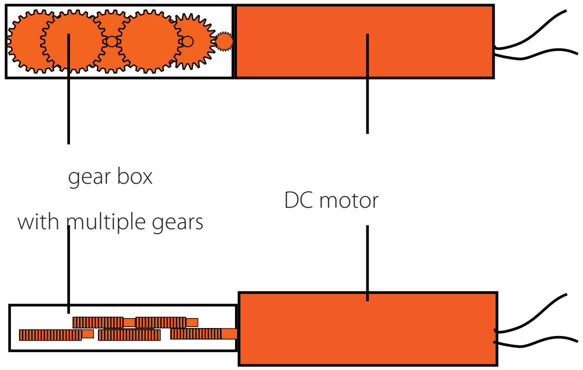


figure 3- 13

Configuration of new conveying mechanism

Colouring the filament

The colourizer that functions as colouring the filament beforehand melting sub-function. In principle, through the contact between the filament and hard felt material, pigment are coated on the surface of filament and mixed up afterwards. Through multiple trials with different kinds of pigment and coating mechanism, the configuration is generated accordingly. A series of experiments can be found in appendix (A15, the experiments of colouring).

Colourizer contains one route part made of hard felt material, which functions as coating and contacting. One pigment storage surrounds the hard felt material for storing and transmitting pigment. One outer cover is needed for protecting and sealing the ink storage. The geometric structure is shown below. In order to ensure the amount of pigment that are coated on the filament, contact part is preferred encircling the filament. Figure below shows basic configuration.

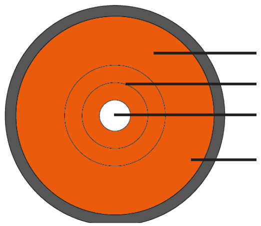


figure 3-14

Configuration of colourizer

Shaping the outcome

Refer to typical polymer extrusion industry, dies are used in polymer processing that serve the purpose of imparting a specific cross-sectional shape to a stream of polymer melt that flow through them (Zehev Tadmor & Costas G. Gogos, 2013). They are primarily used in extrusion process to continuously form polymer products, which are positioned at the exit end to resolve the form of the outcome.

The more molten the polymer is, the more efficient the shaping is. Therefore, melting area is settled right next to the die, which can be seen as an unity.

The dimension of outcome is corresponding to the die, which requires different dies for the product. Thus, manipulation of the form of the output can be realized through changing the shape of the die.

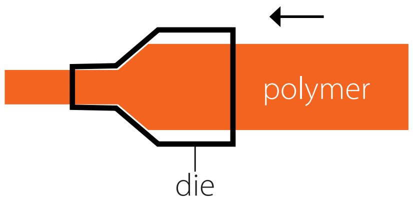


figure 3-15

Shaping the polymer

Varying shapes of the die can be achieved by either directly replacing the die or deforming the die. Through a comparison of these two methods, deformable die overwhelms replaceable one on efficiency, safety and intuition of usage. However, the results from deformable die is not proved yet which need further discussion. Therefore, deformable die is temporarily prefereable for changing the shape of the outcome. (A16, comparison of varying the shapes of die).

Configuration design

Based on previous product ideas for fundamental functions, the basic configuration of the product can be distilled. The melting and shaping are closely connected, which is called extruder here. Extruder, conveying mechanism and dosing of filament are connected through a conduit for transporting filament. Meanwhile, leads respectively connect conveying mechanism and extruder with electric board for the sake of power. Power could either be a internal battery or external power source that connected through cable.

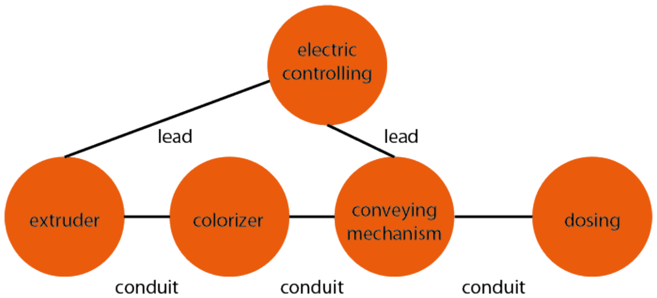


figure 3- 16

Geometric configuration of product

As an uncertain component, no specific sequence or connection is needed for colouring mechanism as long as it contacts with filament at any moment. However, considering the replacement of colour cartridges, the closer the colouring mechanism to melting area, the less unexpected coloured filament will be, which enhance the efficiency of replacement. Thus the colouring mechanism is setted next to extruder. The figure shows basic geometric configuration.

Furthermore, in order to embody abstract configuration, the rearrangement thereof is processed. Three criteria that come from design brief chapter should be imposed. (requirements 9, 10, 11).

As the result, the configuration is embodied as shown (figure 3- 17). Extruder is pinch gripped by thumb, index finger and middle finger. The dosing part stays on the back of hand. They are connected by one part that contains colourizer, conveying mechanism, conduit and cables.

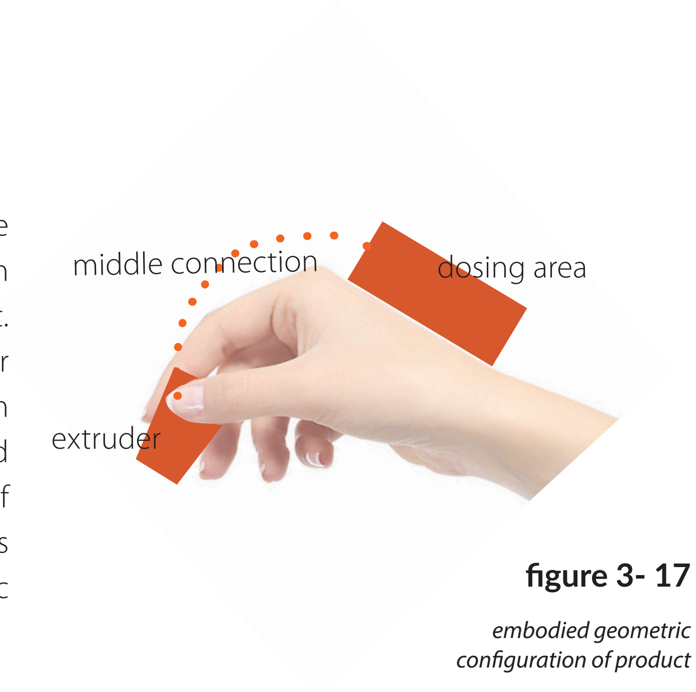


figure 3- 17

embodied geometric configuration of product

The following conceptualization will start with the configuration that is shown above.

PHASE 3

In this phase, the concept ideas are generated and reorganized into concept. Through the finalization of the concept, embodiment proposal is created. In the end, the validation of concept is done for evaluation of the product.

COVERPHOTO

LIX PEN official commercial - creating 3D object with LIX pen

Embodiment Design

Introduction

This chapter includes the process from abstract product ideas and geometric configuration to explicit design. It contains generation and reorganization of several concepts and the evaluation thereof. Accordingly, one concept is further developed into embodiment proposal. The chapter will end up with the elaboration of detailed proposal.

Concepts

Based on foregoing product ideas and geometric configuration in previous chapter (page 35), concepts are generated accordingly. They are reorganized and further developed into three concepts.

Three concepts are differentiated based on the different ways to connect the extruder and dosing area. One criterion is imposed on the conceptualization which is users should be able to adjust product to adapt the dimensions for different situations. (requirement 16)

The 3D model of three concepts are shown beside. Elaboration of three concepts are shown in the appendix (A17, explanation of three concepts). In order to select one concept for further development, one user test is performed with three 3D models. Three concepts are evaluated based on extensibility, stability, flexibility and smoothness when using the product, degree of fitting in hand when holding the product, appearance and compactness of the product (A18, the user test of three concepts). As the result, concept one prevails on most of the criteria that is selected as the final concept.

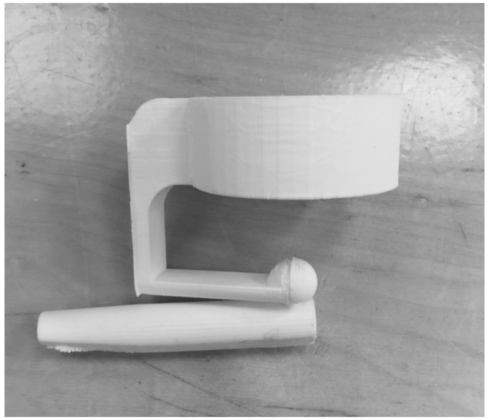


figure 4- 1

Concept 1

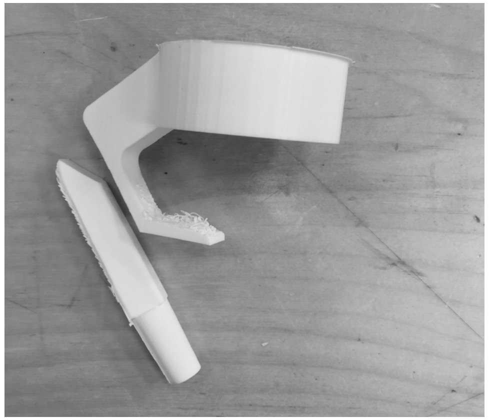


figure 4- 2

Concept 2

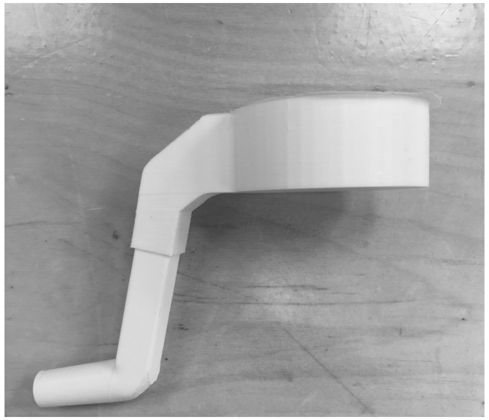


figure 4- 3

Concept 3

Concept finalization

The images show the embodiment proposal. After all necessary parts and their principles were elaborated during several iterations, the parts got defined.

The design was mainly split into three different segments, two individual parts and one connection joint. Those segments are following elaborated. In the end the embodiment proposal was changed to an actual prototype together with a list of recommendations for a final design.

dosing part

Dosing area is the part that stays on the back of hand.

extrusion part

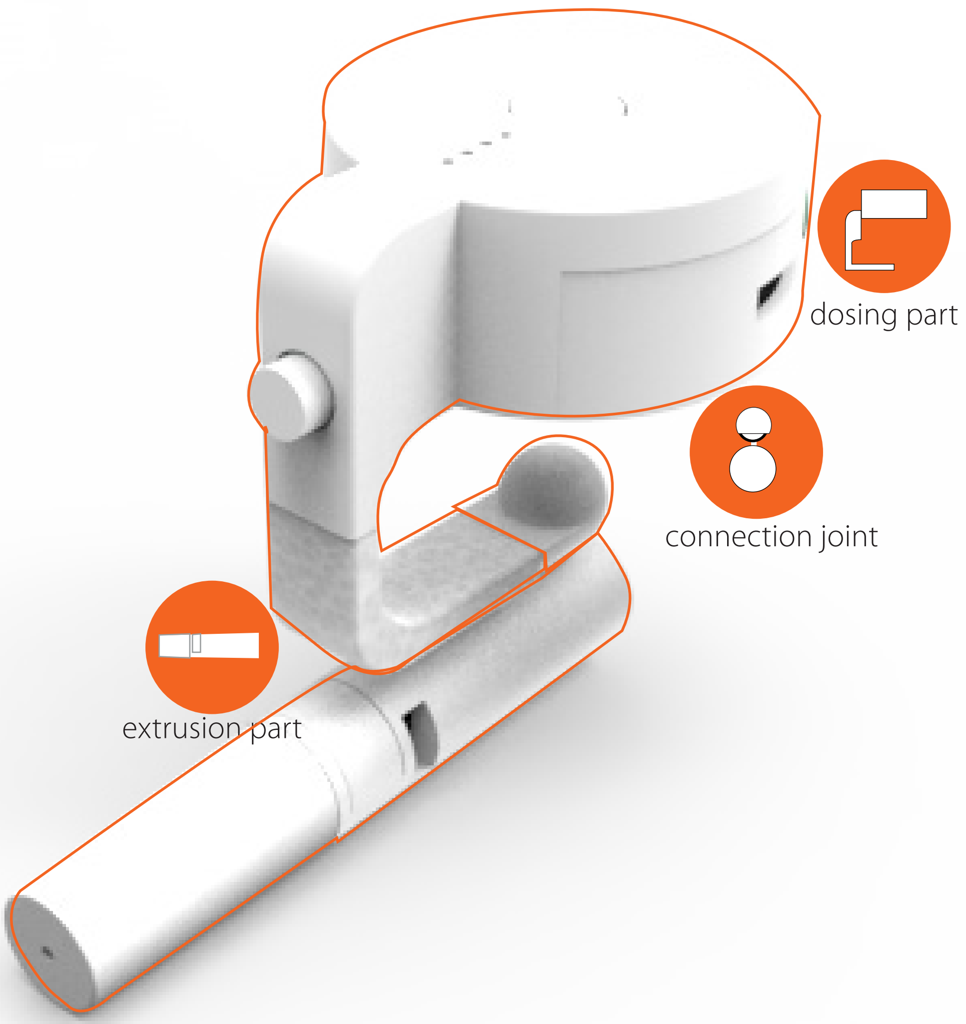
Extrusion part is the part that users hold and move.

connection joint

Connection joint is one ball joint that connects the dosing part and extrusion part

figure 4- 4

Embodiment proposal



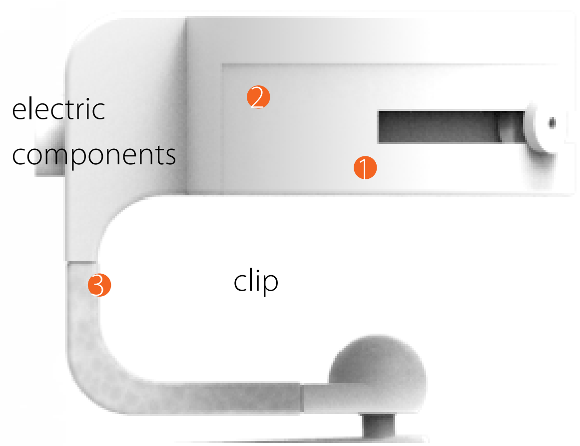
Dosing part

Dosing part stays on the back of hand. It includes the storage of filament (1) and main electric components (2). Entire dosing part is clipped on the side of hand.

Filament storage

Filament storage involves one spool (4) that the filament is entwined on. It stays underneath the part that contains electric components and battery. The heating that caused by battery can be separated from back of hand. The top surface of dosing part contains main switch (5) of the product and four indication lights (6).

One cap (7) wraps the spool. It directly contacts with back of hand. There is one strip of empty space functions as a slide. One cylinder (8) with the hole in the middle moves alongside the slide, which acts as exit of filament. The moveable cylinder allows users adjust the direction of filament in different situations. The cap is attached on the product through several magnets.



1 Filament storage *2 Electric components*
3 Clip

4 Filament storage *5 Switch button* *6 Indication light*
7 Cap *8 Exit of filament* *9 Magnets*

figure 4- 5

The side view of dosing part

figure 4- 6

The filament storage

Clip

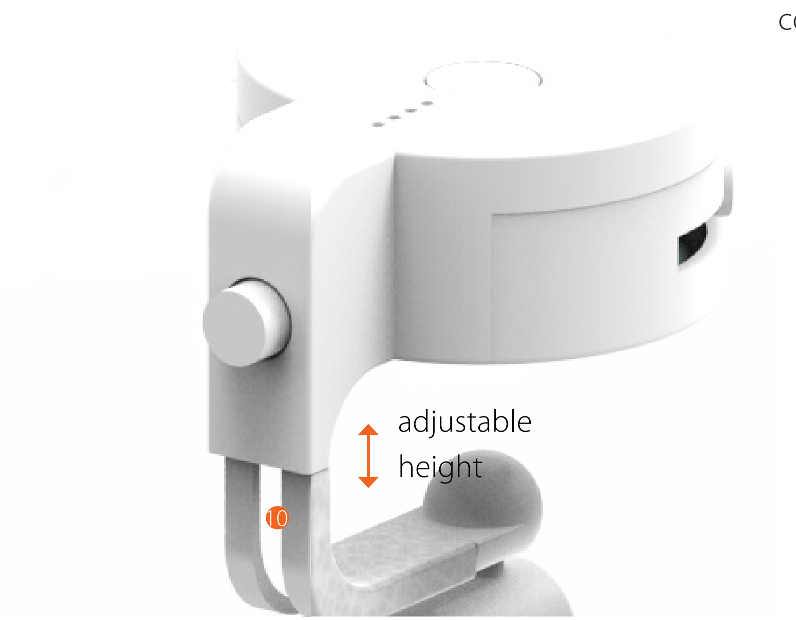
The dosing part stays on the back side of the hand through one clip. It enablers dosing part stabilize during the usage. In order to fit the thickness of different hands, the height of clip is adjustable.

Connection joint

As previously described, dosing part stays still on the back of hand. The ball joint connects extrusion and dosing part, while enablers the flexibility of extrusion part at the same time. Through twisting extrusion part, the angle with dosing part shifts correspondingly.

Extrusion part

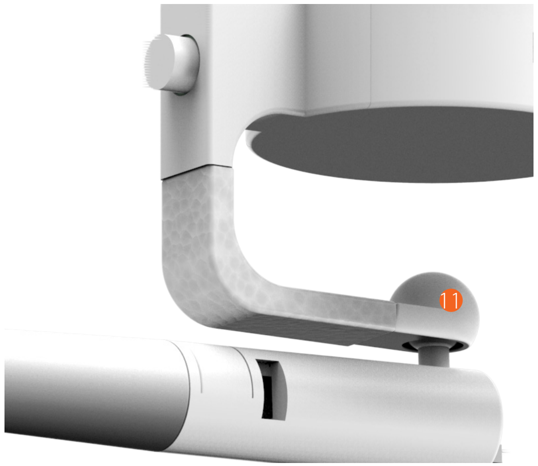
The extrusion part is held and moved by pinch grip. It functions as conveying, colouring, melting and extruding the filament. It includes one conveying mechanism (12) inside, one replaceable colouring mechanism (13) that is inserted on and gripping area (14) at the end of extrusion part.



10 *Extensible clip*

figure 4- 7

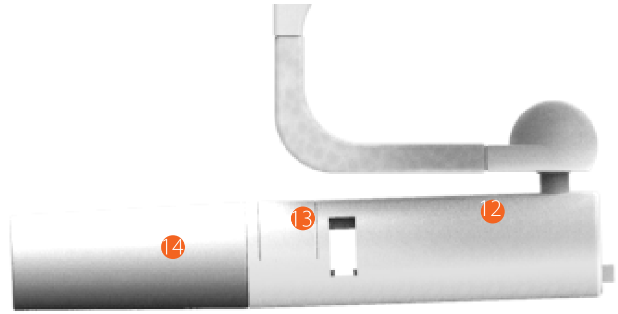
The attachment clip



11 *Ball connection joint*

figure 4- 8

The ball connection joint



12 *Conveying mechanism*
13 *Replaceable colouring mechanism*
14 *Gripping area*

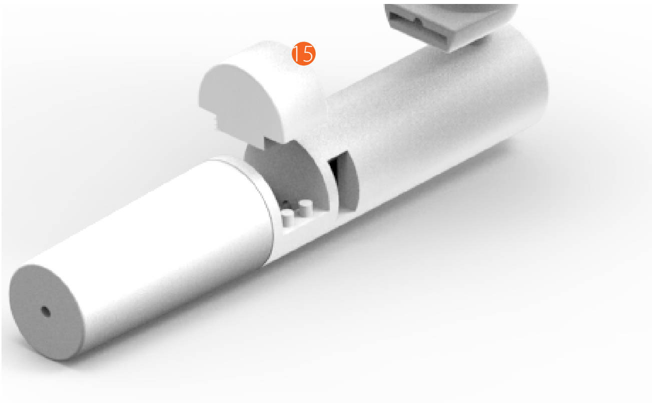
figure 4- 9

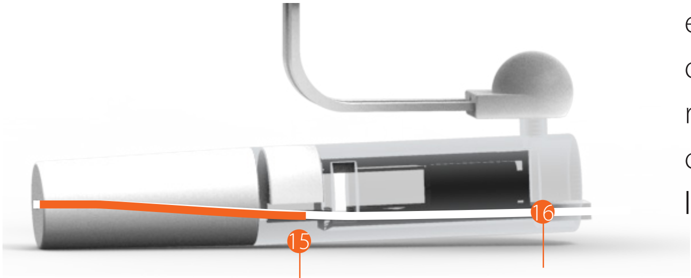
The extrusion part

Colouring mechanism

The colouring mechanism (15) is designed as a module that can be replaced when users want to change another colour. Various colours can be generated through coating ink on white filament. It is inserted right next to the gripping area.

It contains one route part made of hard felt material, one pigment storage surrounds the hard felt material and one outer cover for protecting and sealing the ink storage. The filament is conveyed through the route of colouring mechanism before going inside gripping area. Through contacting with hard felt material, different colours are coated on the filament.





15 *Replaceable colouring mechanism*

16 *The filament*

figure 4- 10

Colouring process

Conclusion

At the moment, the embodiment proposal is in the stage where all principles, necessary parts, dimensions are decided upon and can be argued. Theoretically, the design will suffice all requirements.

Based on foregoing proposal, all the segments are elaborated during the following phase. All the parts of the product are detailed, prototyped, tested and revised. In the end the embodiment proposal was changed to an elaborated design together with a list of recommendations for a final product.

Product design

Introduction

In this chapter, the product is further clarified based on previous embodiment proposal.

A general explanation about the main parts can be found. The following content of this chapter provides more detailed information about the design choices that have been made.

Final design

The final design is shown in figure 5- 1. It shows a product that can be stabilized on the hand while creating three dimensional object in the air. The part that changed since the embodiment design are discussed in this chapter.

Dosing part

The dosing part is attached on the back of hand. It stores filament and contains rechargeable battery as well as main electric components inside.

Extrusion part

The extrusion part is designed to be pinch gripped and moved by users. It contains conveying mechanism to transport filament and colouring mechanism that coats ink on the filament

Connection joint

Connection joint connects the dosing part and extrusion part. It enables users freely move the extrusion part while stabilizing dosing part.

figure 5- 1

The final design

Dosing part

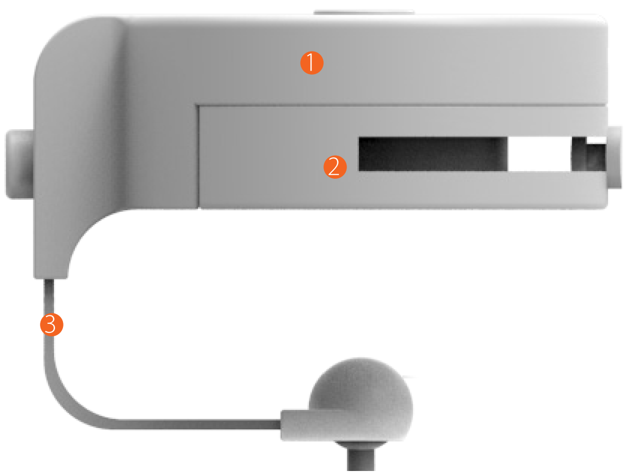
The dosing forms an evident key element, being one of the parts constantly connected to the user.

The dosing part is divided into three detachable parts, the main body (1) that contains filament, electric board and rechargeable battery, the cap (2) that enclose the previous part and one extensible clip (3).

Main body

The main body of dosing part contains one hollow space (4) in the middle. It contains the holder (5) for electric board (6) and rechargeable battery (7). The LED lights (8) and main switch button (9) are configured on the electric board which is able to be recognized from the top of main body. One plug (10) in the figure connects power cable for recharging.

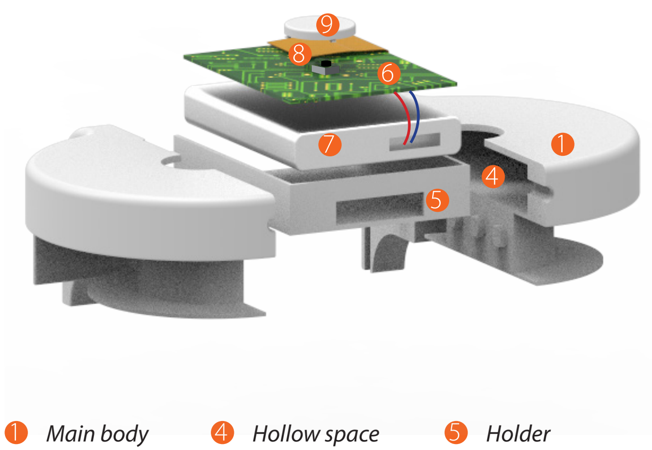
Furthermore, one bearing surrounds the cylinder that underneath the holder functions as the spool (11) for storing filament. The diameter thereof is 17mm. It allows users to store around 1500mm of filament which lasts for at least 12 minutes for continuous usage.



1 *Main body* 2 *Cap* 3 *Extensible clip*

figure 5- 2

The entire dosing part of final design



1 *Main body* 4 *Hollow space* 5 *Holder*

6 *Electric board* 7 *Battery* 8 *LED lights*

9 *Switch button*

figure 5- 3

The explosive view of main body

10 *Recharging plug* 11 *Filament spool*

figure 5- 4

The entire dosing part of final design

Cap

The cap enclose the main body while contacting with back of hand. It attached on the main body through magnets (12), which is convenient to be detached when refilling filament.

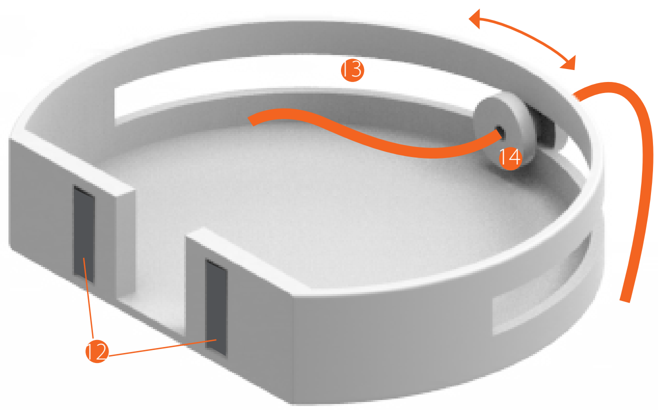
One strip of empty space functions as a slide (13). One cylinder (14) with the hole in the middle moves alongside the slide, which acts as exit of filament. The moveable cylinder allows users adjust the direction of filament in different situations. The range thereof is 180 degree.

Extensible clip

The product is attached on the hand through one clip (15). It is extensible alongside the track (16) inside main body. The thickness of hands varies from 23mm to 29mm among 90% people (Dined, 2016). Accordingly, the clip is made which mainly focussing on an increase of the stiffness and elasticity thereof.

As the result, one bent spring steel act as clipping component. Through loosing the bolt (17), the clip can be vertically adjusted alongside the track for 6mm. Furthermore, the flexibility of spring steel itself could act as adjustment as well. The spring steel is covered by one piece of rubber (18) for the sake of comfortability.

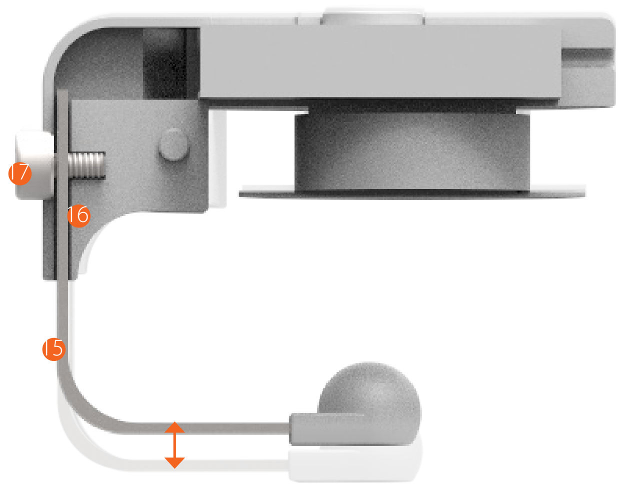
The thickness of spring steel is 1.5mm based on the simulation and several tests. (A19, simulation of steel). The width thereof is 15 mm that enables users to carry at any position of hand without discomfort.



12 *Main body* 13 *Hollow space* 14 *Holder*

figure 5- 5

The entire dosing part of final design



15 *Steel clip* 16 *Track for clip* 17 *Bolt to fix clip*

figure 5- 6

The profile of extensible clip

Extrusion part

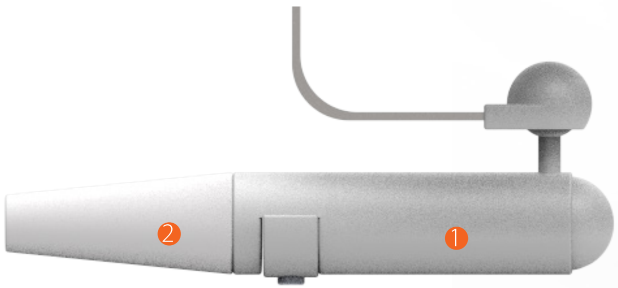
The extrusion part is designed to be pinch gripped and moved by users. It mainly includes two parts. The first part is aluminium body (1) that contains conveying mechanism to transport filament and colouring mechanism that coats ink on the filament. The second part (2) is the area that users grip.

Aluminium body

Aluminium body includes two main functions. It contains the conveying mechanism (3) inside, which functions as transporting the filament from dosing part to the end. Through inserting one hemisphere cap (4), conveying mechanism is fixed inside aluminium body. Another function is colouring mechanism (5) that is inserted on the body. The colouring mechanism coats various ink on the filament.

Conveying mechanism

As described in conceptualization phase (page 38), conveying mechanism is one gearbox with multiple gears (6) inside that is driven by a coreless driving motor (7). Besides, one symmetric holder (8) is designed for containing gearbox, forming the conduit for transporting filament and loading electric board (9) for heating.



1 *Aluminium body* 2 *Gripping part*

figure 5- 7

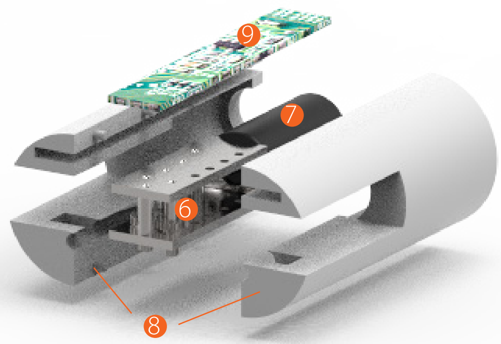
The entire extrusion part of final design

3 *Conveying mechanism* 4 *Hemisphere cap*

5 *Colouring mechanism*

figure 5- 8

The disassembly of extrusion part



6 *Multiple gears* 7 *Coreless driving motor*

8 *Symmetric holder* 9 *Electric board*

figure 5- 9

The disassembly of conveying mechanism

Colouring mechanism

Filament is inserted inside the holder through the conduit (10) thereof. After going through conduit, filament contacts with the conveying gear (11), which functions as driving the filament.

The special design of colouring mechanism eliminate the needs of taking along filaments with different colours. Through coating different pigment on white or transparent filament, the colour of outcomes changes correspondingly.

The colouring mechanism (12) is inserted at the end of aluminium body, which is next to conveying mechanism.

It contains one shell (13) that functions as protection of colouring mechanism. Two holes (14) on both sides form the conduit for filament to go through.

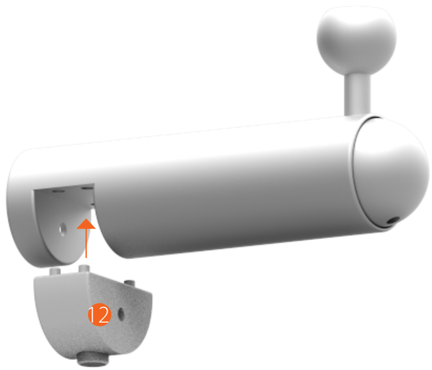
Inside the shell, there is one piece of sponge that stores pigment. It surrounds one hard felt tube that contacts with filament. The hard felt tube coats pigment on the filament through the friction in between. There is one cap (15) at the top of shell that users could refill pigment.

6 Multiple gears *7 Coreless driving motor*

10 Conduit for filament *11 Conveying gears*

figure 5- 10

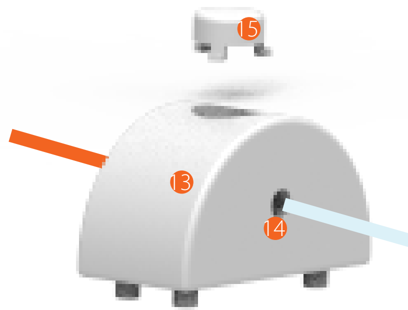
The conveying of filament



12 Colouring mechanism

figure 5- 11

The position of colouring mechanism



13 The shell of colouring mechanism *14 Holes as conduit*

15 Refilling cap

figure 5- 12

The detail of colouring mechanism

Gripping area

Users pinch the gripping area to move the product. It is one hollow circular truncated cone (16). It is connected with aluminium body through on connection component (17). Since the optimal diameter for precision grip is 8mm to 13mm, the tip of gripping area is 10mm. The length of gripping area is 40mm that is suitable for different situations. Moreover, the button (18) for extrusion is setted inside the hollow space of gripping area. Users could easily press the button for extruding filament.

Furthermore, the gripping area functions as melting of the filament as well. As shown, one cable connects ceramic tube (20) and electric-heating components. Through heating up ceramic tube, the heat will be transferred on the stainless steel tube (21). The filament is molten while going through the steel tube.

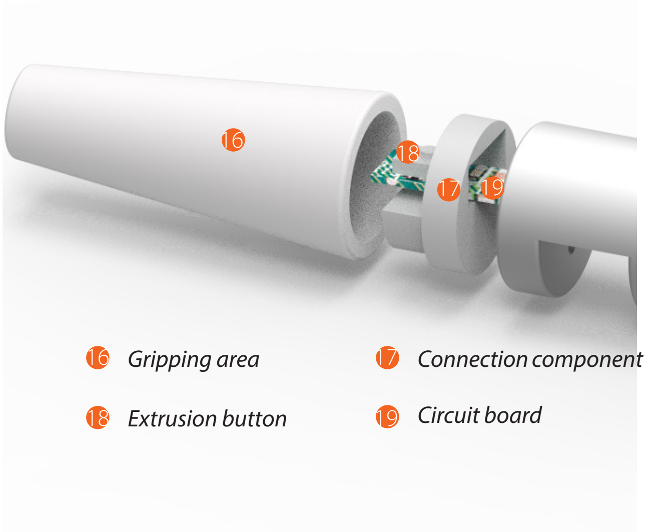


figure 5- 13

The disassembly of gripping area

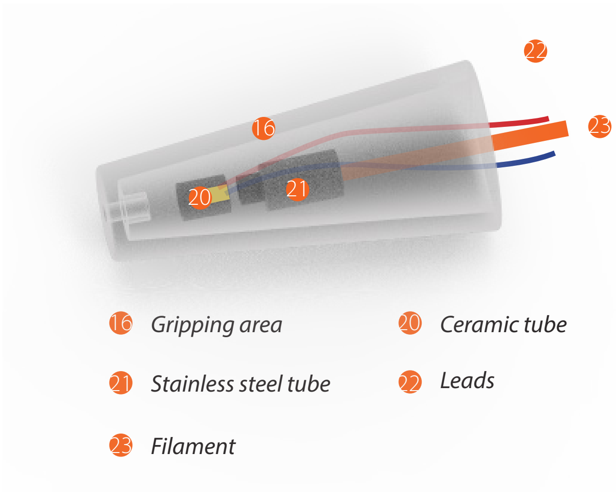


figure 5- 14

The configuration of gripping area

Material

Since grip area constantly contacts users, the gripping area is designed to provide as much comfort as possible, while ensuring enough freedom of movement for operating the product. Thus, the softness is significant for the material. Meanwhile, the temperature is around 200 degree when melting filament, which requires the heat resistance of the material.

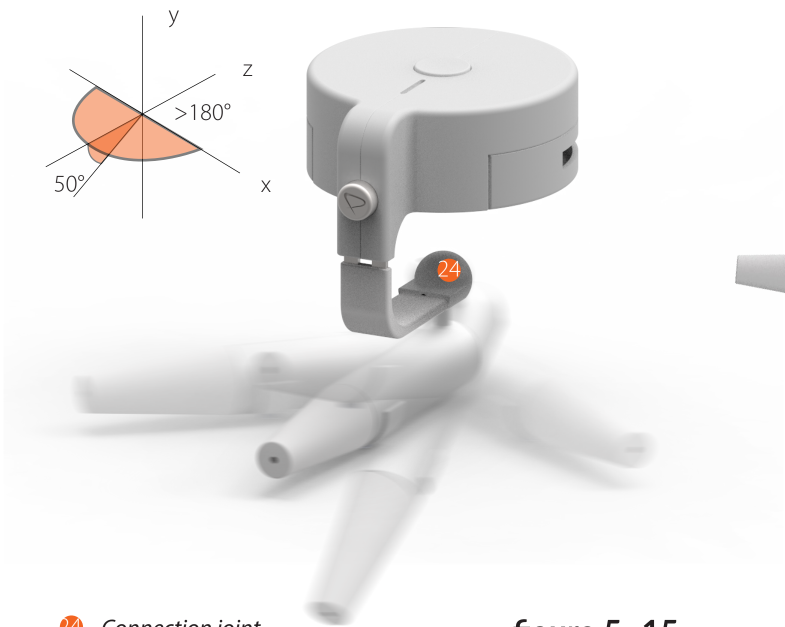
Accordingly, silicone elastomer is selected as the material. Silicone elastomer has low hardness and easily deformable. Silicone has low thermal conductivity which avoid hurting users' finger which is caused by high temperature. Meanwhile it has constancy of properties over a wide temperature range of −100 to 250 °C, which qualified the required temperature for heating.

Connection joint

Connection joint connects the dosing part and extrusion part, while enablers the flexibility of extrusion part at the same time. Through twisting extrusion part, the angle with dosing part shifts correspondingly. Wherever users put the product on, the ball joint nearly stays in the centrally sunken part of palm. The scope of the rotation that extrusion part can perform is shown.

Overall

On the whole, dosing area stays on the back of hand through the extensible clip. Extrusion part is pinch gripped which could pivot on the connection joint at the centre of palm. The filament goes out of the dosing part and is inserted into the extrusion part. Figure below shows overall image.



24 *Connection joint*

figure 5- 15

Connection joint allow s extrusion to pivot on

figure 5- 16

Overall image of product

Validation

Introduction

The proposed design needed some validation to show what works, and where improvement is needed. The tests and the results that were being used for this validation are shown in this chapter.

To validate the design choices and therefore the final design, some testing was done. The executed tests focussed on all aspects of the designed ice boat. The main things that were taken into account are distilled from design specification.

Since the limited time, complete workable prototype is not finished. This had some implications for the testing.

Evaluation

Although fundamental principles and related configurations have already be validated separately and synthesized into one final design, it was not enough to validate the design in terms of creating three-dimensional object in the air as a whole, especially several comfortability and controllability related factors which are close to the experience of users.

To find whether the design achieved to "comfortable holding and operation" and "high ability to control" in real scenes, one user test is done with designers. Appearance prototypes are made for the test to compare with current LIX pen. The prototype imitates the way that product is attached on the hand and the experience that product extrudes filament.

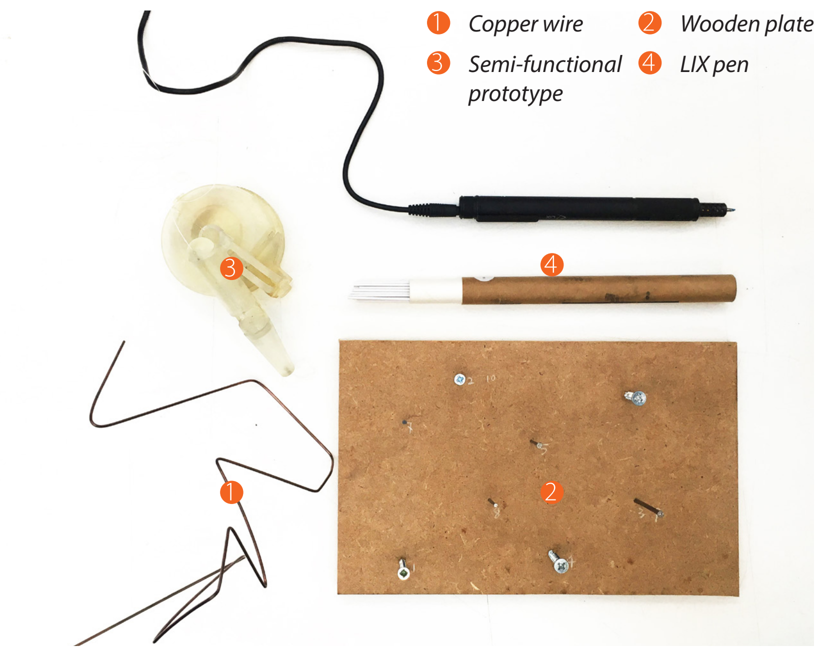
Five designers are interviewed for feedback and the interaction are observed during play. Interview recordings, video footages, and photos were collected for analysis.

Set up

figure 6- 1

The set up of user test

Preparation



There are four instruments are used for the test. Two of them construct two different contexts, One free-bent copper wire (1) which simulates trajectory of spatial motion. One wooden plate (2) with various nails on it construct the situation that extruding filament among various spots. One semi-functional prototype (3) is made for testing. Current LIX pen (4) is used as comparison.

Cooper wire

One copper wire is freely bent into random shape. It mocks one result for creating three-dimensional object.

figure 6- 2

The copper wire

Wooden plate

There are eight screws on the plate with different heights. Each screw represents one spot that need to be reached. There are one or two numbers right next to each screw, which indicates the order of the reaching process.

figure 6- 3

The wooden plate

Prototype

One semi- functional prototype is made for testing. Participants are able to move the prototype while attaching the it on the hand through one adjustable clip. The majority of parts of the prototype were fabricated in photopolymer resin by 3D printing and then assembled. The prototype goes through slight polishing but stays unpainted before the tests.

Furthermore, due the limitation of time, the extrusion of filament is not able to realized. Correspondingly, The process of dragging fishing line out of prototype imitates extrusion process.

figure 6- 4

The prototype that is used during the user test

There are several similarities between finishing line and filament. Both of them need to be kept dragging since the softness of material. Furthermore, when extruding filament at each spot, users need to stay for several seconds in order to made the joint stronger. Similarly, the fishing line needs to be entwined on the screw for fixation, which requires participants to stop for several seconds as well.

LIX pen

Current LIX pen is used as comparison with the prototype. Meanwhile, it indicates the exact experience of extruding filament while dragging fishing line with the prototype.

figure 6- 5

The LIX pen that is used during the user test

Questionnaire

One questionnaire (A21, the questionnaire for user test) is formulated for evaluation. It includes two parts which are corresponding to two contexts. Each part includes seven factors that participants need to rate from -3 to 3, which represent not at all to excellent. All the factors are extracted from design specifications that the product should meet.

Comfortability- related factors include stability, flexibility, degree of adaptation, degree of relaxation, instinct of usage, professionalism of appearance, while controllability- related factors are smoothness, precision and efficiency. Moreover, the stability, degree of adaptation and instinct of usage are evaluated by both contexts since these factors are dynamic which differ while making different actions.

Procedure

A brief of 3D pen and the project is given to the participants at the beginning. After knowing the purpose and the process of the test, participants carry on two individual tasks with both LIX pen and the prototype. Each task is executed by LIX pen first then prototype. Participants need rate the experience after finish each task by filling up questionnaire..

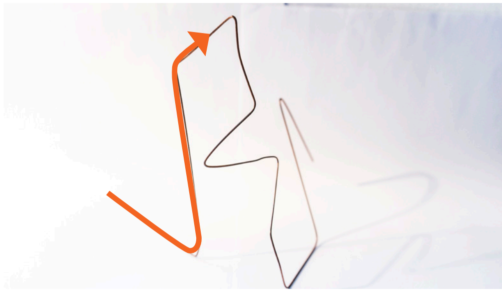
Performing session

A short presentation of the whole set of prototype provides participants a clear understanding of the entire concept and what they could do with the prototypes. After that, they are required to perform two tasks with both prototype and current LIX pen.

The first task is the evaluation for the comfortability of spatial movement. Participants need to move both the prototype and current LIX pen alongside the copper wire which imitates creating process. The curve of copper wire ensures that participants need to perform multiple-directional movement with hand. Afterwards, two experiences are rated by filling the first part of questionnaire. A short interview accompanies with the rating for the explanations of exact ratings.

figure 6- 6

Participants compare final design proposal and current LIX pen by following the trajectory of copper wire



The second task is the evaluation for both comfortability and controllability of spatial movement while extruding filament. Participants are asked to connect all the screws on the plate with both prototype and current LIX pen based on certain order. Then two experiences are rated by filling the second part of questionnaires with a short interview at the same time.

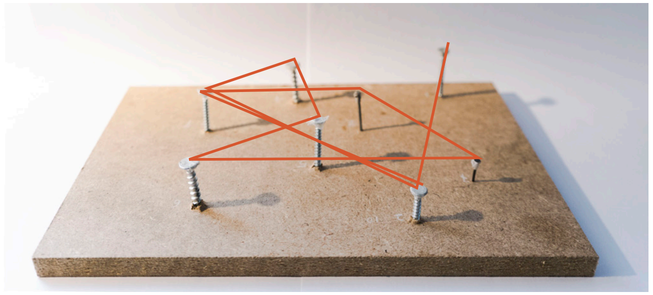


figure 6- 7

Participants compare final design proposal and current LIX pen by connecting all the screws with certain order

Participants

There are five participants (figure X) are involved into the evaluation test while all of them are designers, which includes two product designer, one strategic designer and two designers for interaction. Three of them have used 3D pen before. All of them have experience of sketching and making three dimensional models.

NAME	GENDER	AGE	EXPERIENCE OF 3D MODELLING
Boyu	♂	26	4 years
Joost	♂	24	6 years
Garry	♂	24	3 years
Jianyu	♂	25	6 years
Omar	♂	25	3 years

figure 6- 8

Designers involved in the test with certain experience of 3D modelling

Results

Task 1

The first task pays more attention to the comfortability of pure spatial motion that towards multiple directions. Participants transform various gestures when following the wire. Based on the experience, the evaluation that made by participants for each factors is shown below.

Two hexagon represents connections of average ratings for each factor. The bigger of area the hexagon is, the more excellent the product overall performs. As shown in the figure, the experience of the prototype that represents the final design prevails in all the factors except the degree of instinct.

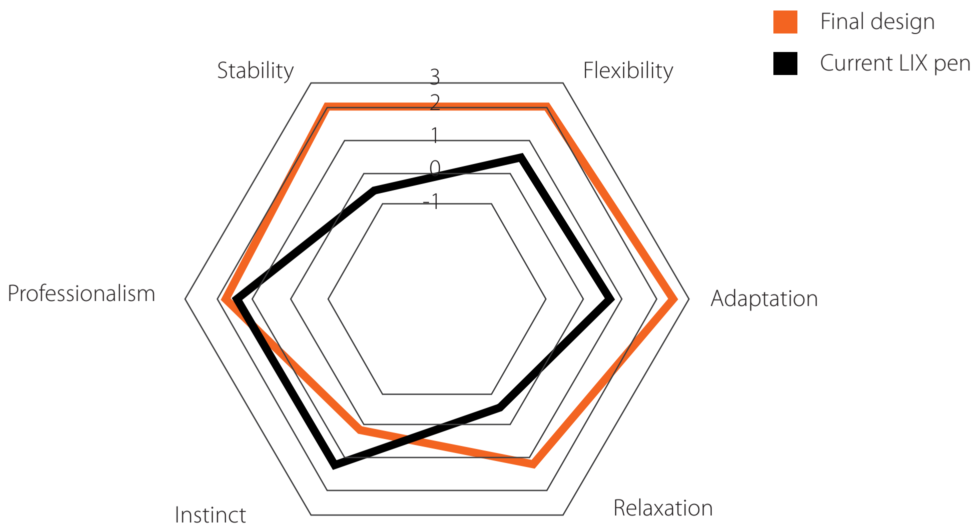


figure 6- 9

Illustration of the evaluation for the first task

Task 2

The second task focus on the experience of spatial motion while extruding filament. Participants not only make spatial motion but also interact with the filament or imitated filament. The motion will be relative simple than previous task. Based on the experience, the evaluation that made by participants for each factors is shown below.

Two hexagon represents connections of average ratings for each factor. The bigger of area the hexagon is, the more excellent the product performs. As shown in the figure, the experience of the prototype that represents the final design prevails in all the factors except the precision.

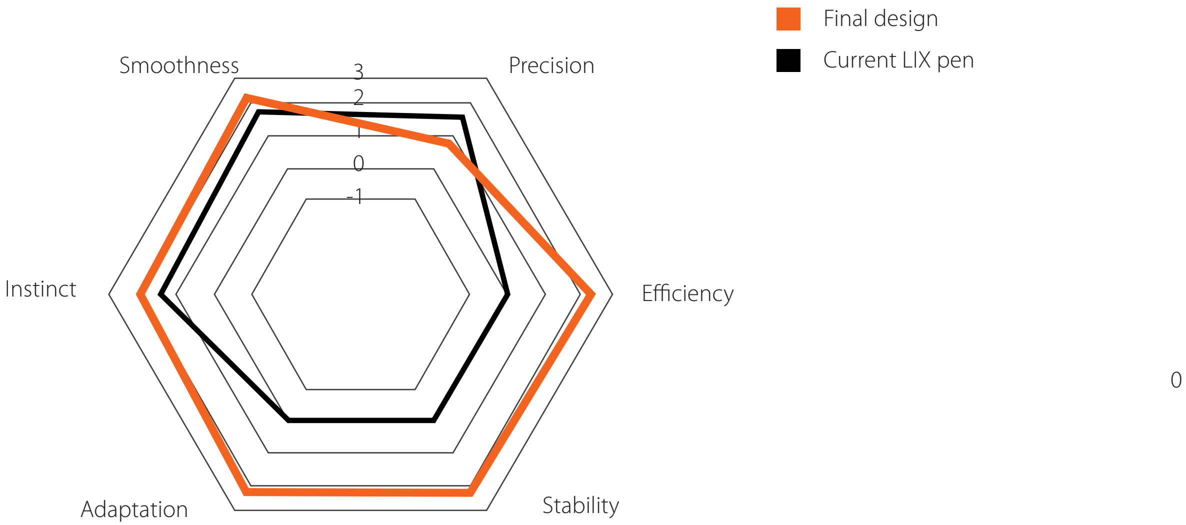


figure 6- 10

Illustration of the evaluation for the second task

Analysis

In addition to the direct rating made by participants, the information collected by interviews during the play session provided abundant materials for analysis. The recordings of interviews before and after the performing sessions were used to support the analysis.

Task 1

The line graph beside demonstrates the difference between final design and current LIX pen for each factor, which directly shows either improvement or weakness of new product.

When performing spatial motion, new product shows huge advantage on all the physical interaction related factors especially stability. It turns out the more comfortability is provided thereof when holding and moving. One frequently mentioned comment is that the centre of weight of new design is stabilized close to the centre of hand, which dramatically enhance the comfortability.

The instinct of the product includes two aspects. The first aspect refers to the easiness of understanding use- method. As described by participants, pen-like form of current LIX pen immensely benefit on understanding of use- method, which is embodied on the rating. However, when further discussing the second aspect of instinct with participants, which is the compatibility with instinct of create three dimensional object, the evaluation differs a lot. It indicates that pen-like form contributes on reducing the learning curve of use-method. After mastering how to use the product, new design is more natural to use.

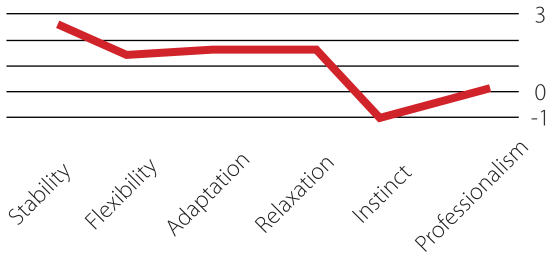


figure 6- 11

The difference of rating between final design and current LIX pen in task 1

Even though average ratings of appearance stay close, the feedback of individual participants is extremely different. Through the feedback from participants, the standard to judge if a product is professional is subjective. Either innovative and unique form or simplistic and general form could be professional.

Task 2

The line graph below demonstrates the difference between final design and current LIX pen for each factor, which directly shows either improvement or weakness of new product.

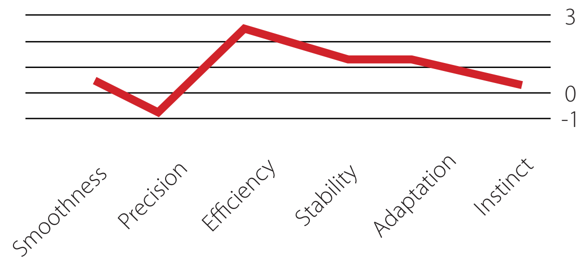


figure 6- 12

The difference of rating between final design and current LIX pen in task 2

Similar to the result in task 1, new product prevails at comfortability- related factors as well. It indicates that the extrusion of filament does not worsen the experience of holding and moving the product.

The ratings for controllability- related factors show contrast. Comparing to current LIX pen, participants fell less precise when using prototype. Through the interview, the main reason is the size of nozzle. The tip of current LIX pen is much thinner than the new product which allows users more convenient to aim targets.

As evaluated by participants, new design is much more efficient than current LIX pen due to filament spool dramatically decrease the frequency to refill,.

Discussion

Even though fishing line is similar to filament in some certain degree, there are still big difference in between, which probably causes misunderstanding and misleading to participants.

Moreover, when dragging fishing line out of the prototype, it frequently get stuck since fishing line is extremely soft and flexible. It affects the smoothness during the test.

On the other hand, since the filament can not harden immediately, which make it liable to break. However, fishing line is much stronger. As the consequence, participants are less careful when using the prototype, which probably affect the experience thereof.

Conclusion

Improvement

Final design shows huge improvement on the stability and efficiency on usage, which indeed benefit on the perceived comfortability and controllability of the usage. Moreover, the physical interaction of final design is more ergonomics.

Weakness

Final design shows the disadvantage on aiming activity especially the targets is relative tiny, which probably causes imprecision when creating.

Validation of conveying mechanism

Conveying mechanism is one of the most important parts of the product. It conveys filament from doing part to the end of extrusion. As elaborated in the final design phase (page 54), conveying mechanism is one gearbox with multiple gears inside that is driven by a coreless driving motor.

Motor

The motor follows the current specification which the diameter is 8mm. It provides 16500 RPM of load speed. The pitch diameter of worm thereof is 1.7mm. Specific specification can be found in the appendix. (AX, the specification of motor)

figure 6- 11

The motor that is used

Gears

Currently, the speed of conveying filament is required to be more than 6mm/s. Furthermore, through the test, the required force to convey filament is 6N.

The configuration of all the gears is shown in the figure X. It totally contains five stages of transmission. The first stage (1) is transmitting the speed from worm (2) of motor (3) to the first wheel. Then it sequentially transmits through each stage and end up with two conveying spur gears (7).

The pitch diameter of each pinion is 1.7mm except the last pinion is 3.2mm. The diameter of first wheel is 2.55mm while the rest three are 4.35mm. The diameter of wheel which interacts with conveying gear is 3.2mm. Through sequential reduction, the ratio of load speed between the worm and conveying gears is approximate 47.3 : 1 while the load torque stays 1 : 47.3. As the result, the conveying speed is 5.8 mm/s while the torque is 5.6N for one single conveying spur gear.

1 Stage 1- 2 *2 Worm of motor* *3 The motor*
4 Stage 3 *5 Stage 4* *6 Stage 5*
7 Conveying spur gears

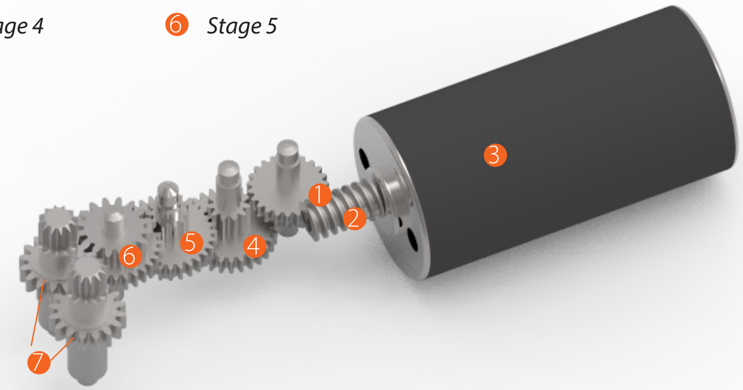


figure 6- 12

The configuration of gears

Gearbox

Based on foregoing configuration, one gearbox in designed. All the gears are configured in between two steel plates (8). Two plates are connected and fixed through four screws. They are further fixed with motor.

Prototype

To test if the conveying mechanism exactly works, one prototype of gearbox is made. The gearbox is tested individually without other parts of the product. The gear box is validated with one 1.75mm PLA filament. As the result, it perfectly suffice to convey the filament.

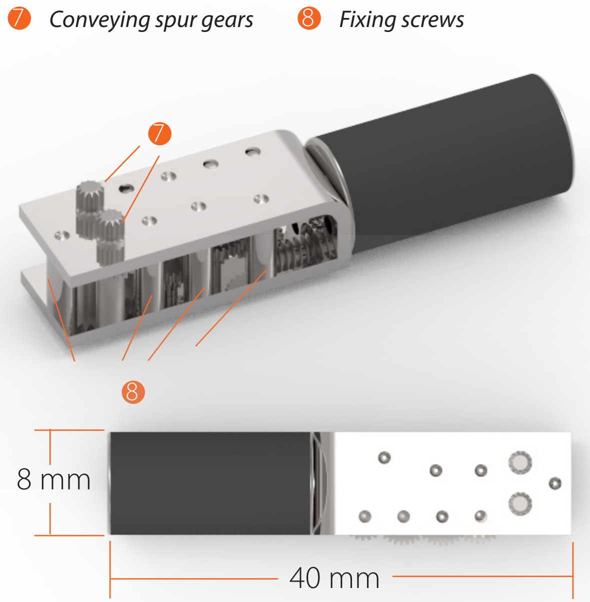


figure 6- 13

The design of the gearbox

figure 6- 14

The prototype of gearbox is used to tested as validation

Conclusion

The design of the creating three dimensional object in the air optimizes the experience for professional designers in the process of physical 3D modelling. Through the comprehensive research and analysis phase, four fundamental aspects, which act as design goals of the project, are discovered. Both the interest and expectation of company and the expectation of users are all-inclusive in these four aspects, which are comfortability, controllability, portability and adaptability.

Explicit interpretation for foregoing four aspects leads to elaborated specifications which guide the design. Most of the respects are all- inclusive.

As the result, one detailed design which facilitates the comfortability, controllability, portability and adaptability in the process of physical 3D modelling is create.

Comfortability

The semi- separate design provides multiple physical interactions with users. They are differentiated based on specific needs for either stabilizing on the hand or being flexible to move around. It enhances the stability of the product while decreasing the effort to operate.

Controllability

Improved volume of filament and rechargeable battery promotes the smoothness during the process. Colouring mechanism transfers refilling the filament to replacing the colouring components, which make it more effortless and efficient to change the colour.

Adaptability

Ball joint connection and extensible clip provides various options to fit different dimensions in different situations. Directly coating pigment on the filament enhances the amount of colours that can be used.

Portability

Rechargeable battery and improved volume of filament allows users to take along the product more convenient.

All in all, the design, as a proposal of way of creating three dimensional object in the air, is able to facilitate entire creating process and has the potential to be an influential professional tool for designers.

Recommendations

It requires further design, development and testing to make a comprehensive product. In principle, colouring mechanism is workable and realistic based on a series of tests. However, It needs more validations and tests which shifts this valuable components to a real product. Even though the gearbox is proved to suffice to convey filament individually, it should be validated together with filament spool in case some implications. All the internal components, such as circuit board, need to be further designed, customized and produced to fulfil the requirements. Specific production of each parts requires further considered.

However, this project with its results can be valuable and inspiring for 3D pen industries and all experimenters. For companies, the rethinking of creating 3D object in the air can be a promising direction, for example, replaceable colouring components and new way to hold the product. For designers, the concept showcased a new possibility of interactions with 3D pen, and is a proposal to immediately visualize and demonstrate ideas in physical way.

Reference

Buijs, J., (2003) ‘Modelling Product Innovation Processes: from Linear Logic to Circular Chaos’, Creativity and Innovation Management, Vol. 12 (2), pp. 766-93.

Roozenburg, N. f. M. and Edkels, J.*, 1995. Product Design ; Fundamentals and Methods. Chichester: John Wiley & Sons.

Branton, P. “Behavior, body mechanics and discomfort”, Ergonomics 12(2): 316-&, 1969

Kuijt-Evers, L. F. M., L. Groenesteijn, et al. Identifying factors of comfort in using hand tools, Applied Ergonomics, 35: 453-458, 2004

P. Gu (2), M. Hashemian, A.Y.C. Nee (1)*, Adaptable Design, 2004

Bert Haskell. "Portable Electronics Product Design and Development", 2015.

Rudolf Arnheim. “Art and Visual Perception”, 1974.

Hammerton, M., & Tickner, A. H. An investigation into the comparative suitability of forearm, hand and thumb controls in acquisition tasks. Ergonomics, 9, 125-130, 1966.

Ravin Balakrishnan, Scott MacKenzie. Performance Differences in the Fingers, Wrist, and Forearm in Computer Input Control, 1997.

Zehev Tadmor, Costas G. Gogos, Principles of Polymer Processing, 2013.

Chan I. Chung, Extrusion of Polymers, Theory and Practice, 2000.

Pahl, G & W. Beitz, Konstruktionslehre; Handbuch fur Studium und Praxis, 2nd edition. Berlin: Springer, 1986, pp. 96- 99.